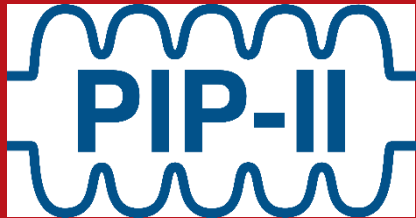




DE LA RECHERCHE À L'INDUSTRIE



Status of and Open Issues with LB650 CM Design

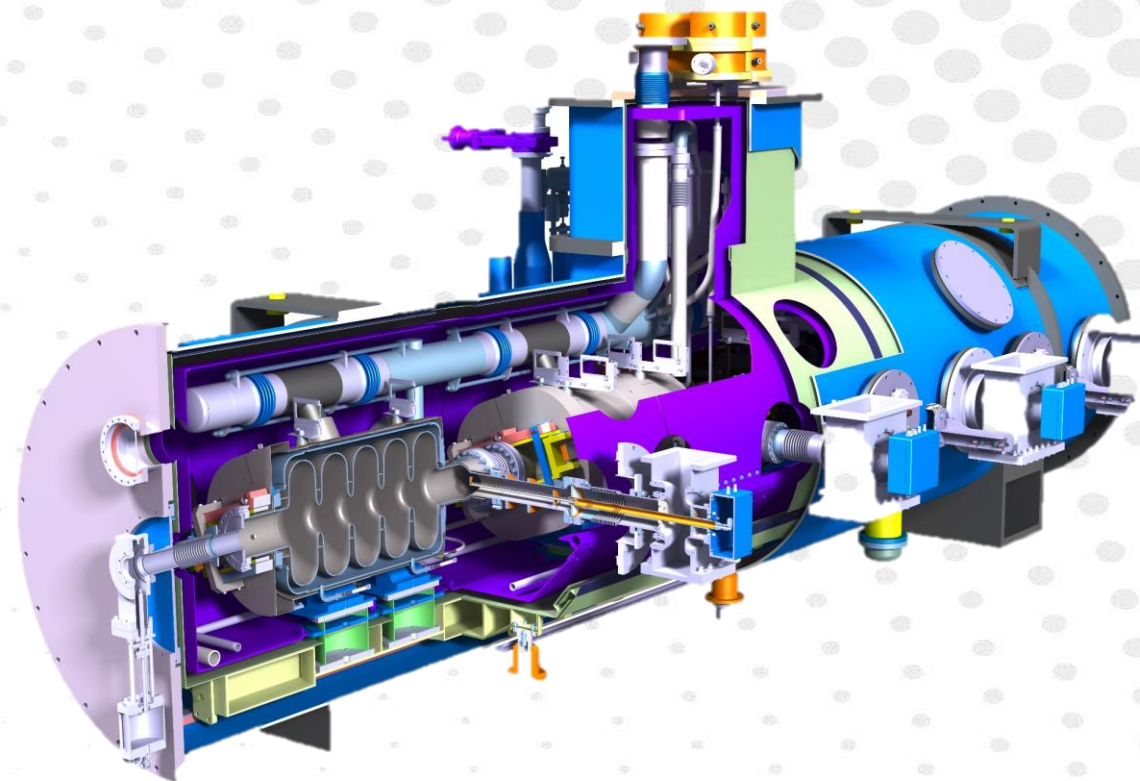
PIP-II Technical Workshop - WG#1 HB650 Cryomodule Assembly

R. Cubizolles

A. Raut

A. Moreau

- ▶ **Vacuum vessel**
- ▶ **Supporting components**
 - Strongback and studs
 - G11 posts
 - Cavity post
 - C shaped element
- ▶ **Helium circuitry**
 - Two phase pipe
 - 5K circuitry
 - Cooling down circuitry
 - Relief line
- ▶ **End pipe tube**
- ▶ **Thermal shield**
- ▶ **Magnetic shield**
 - Global warm magnetic shield
 - Local cold magnetic shield



► Vacuum vessel

► Supporting components

- Strongback and studs
- G11 posts
- Cavity post
- C shaped element

► Helium circuitry

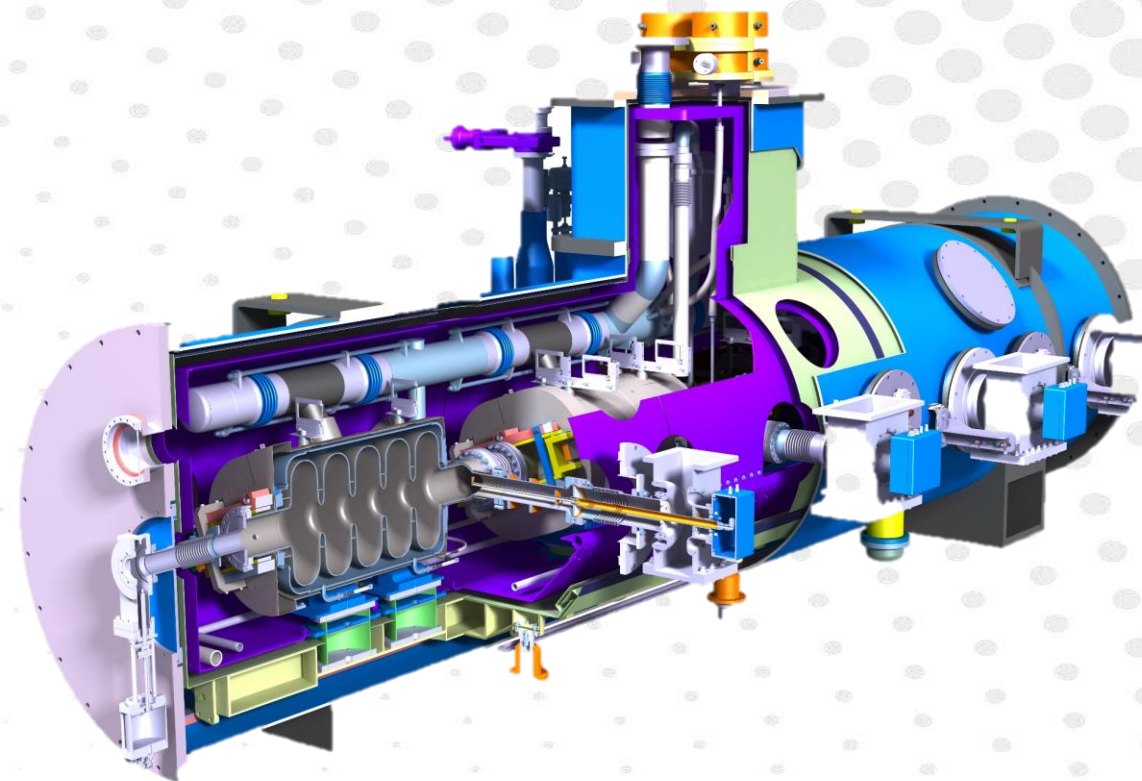
- Two phase pipe
- 5K circuitry
- Cooling down circuitry
- Relief line

► End pipe tube

► Thermal shield

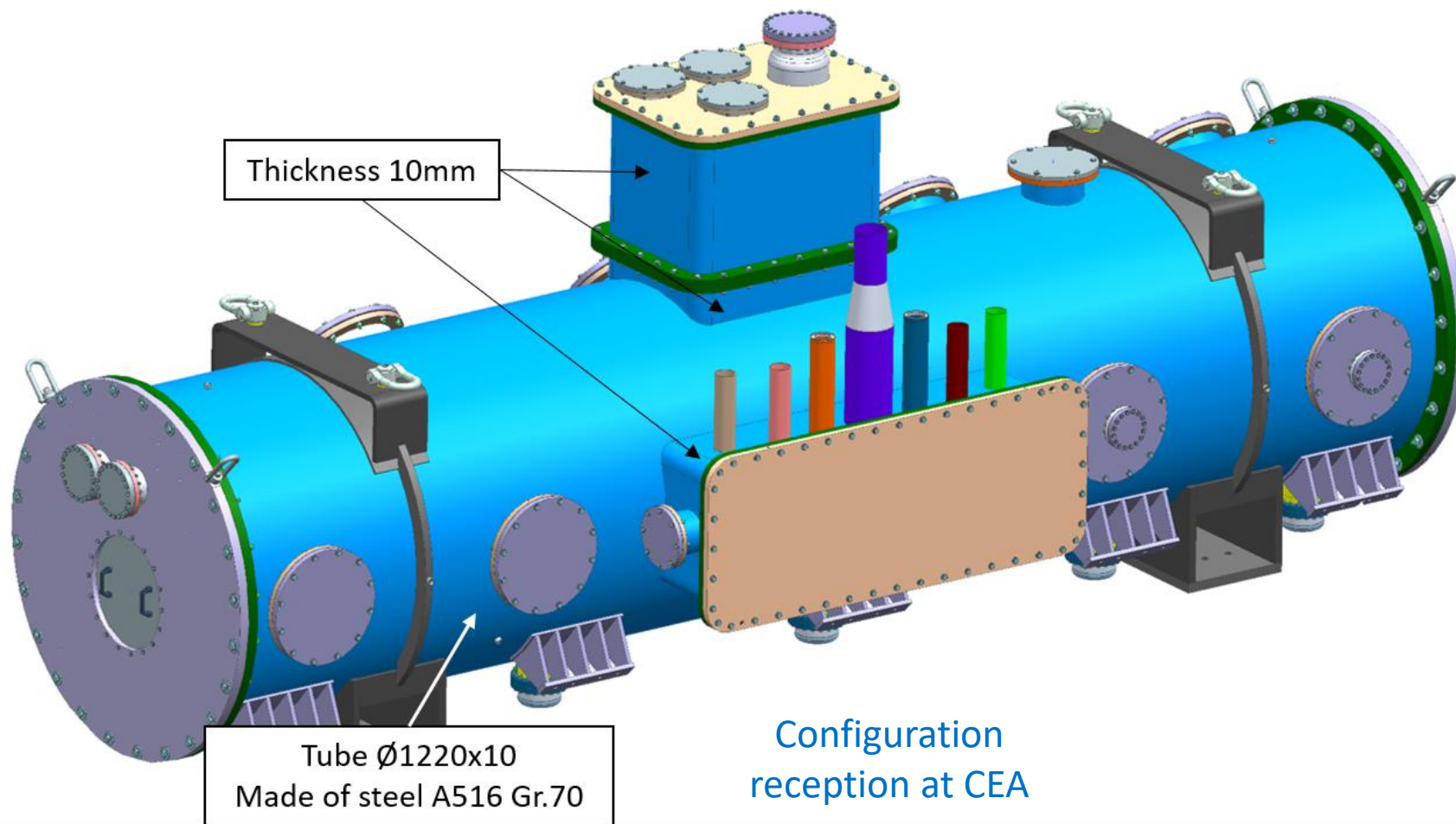
► Magnetic shield

- Global warm magnetic shield
- Local cold magnetic shield



Vacuum vessel main dimensions

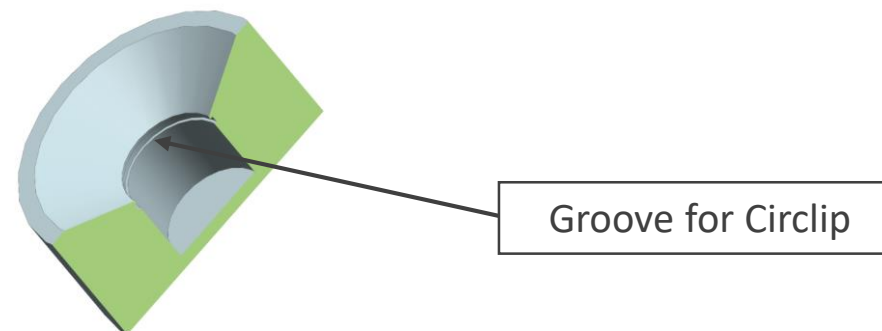
- ❑ Calculation in compliance with ASME BPVC Section VIII on going.
- ❑ All part in 304L except the main tube in steel A516 Grade 70. The top port and side port are in 304L.



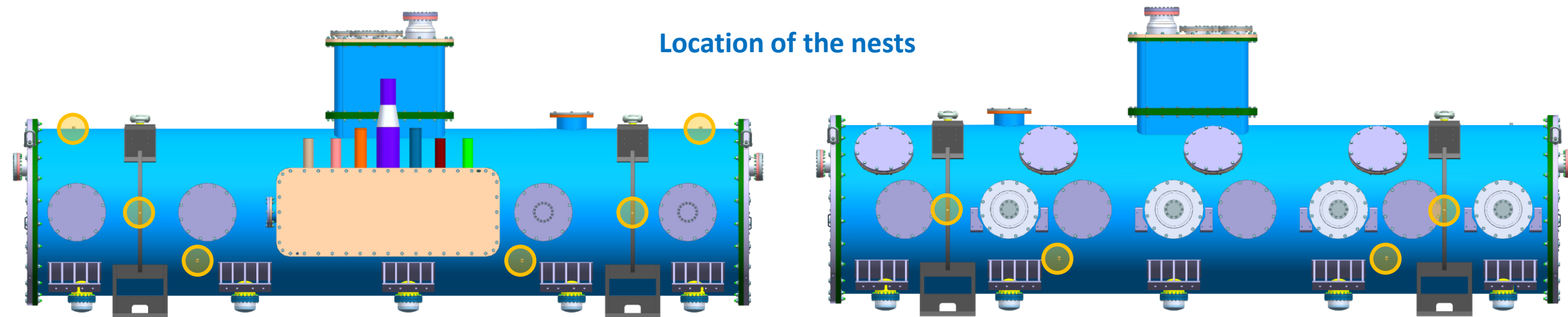
Vacuum vessel alignment nest

- ☐ Nest for alignment target identical to the HB650.
- ☐ Location of the nests :
 - ☐ Two in the top.
 - ☐ Four on the side port side.
 - ☐ Four on the coupler side.

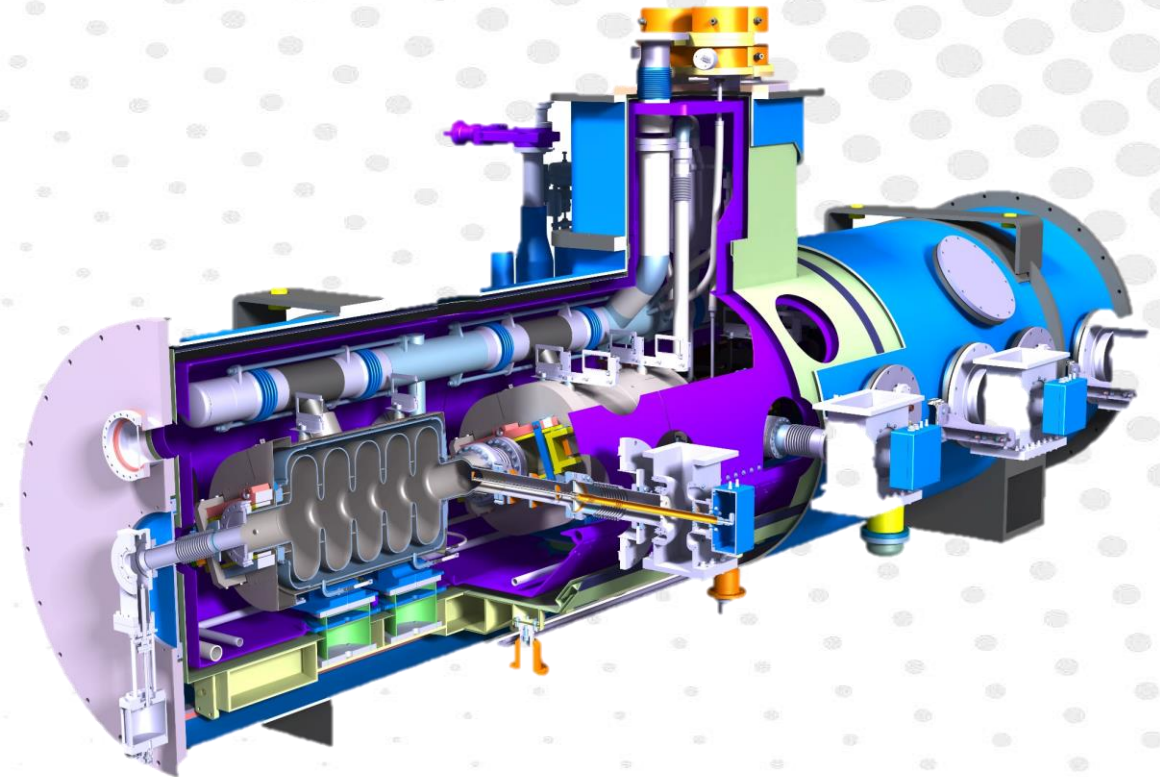
Alignment nest target



Location of the nests

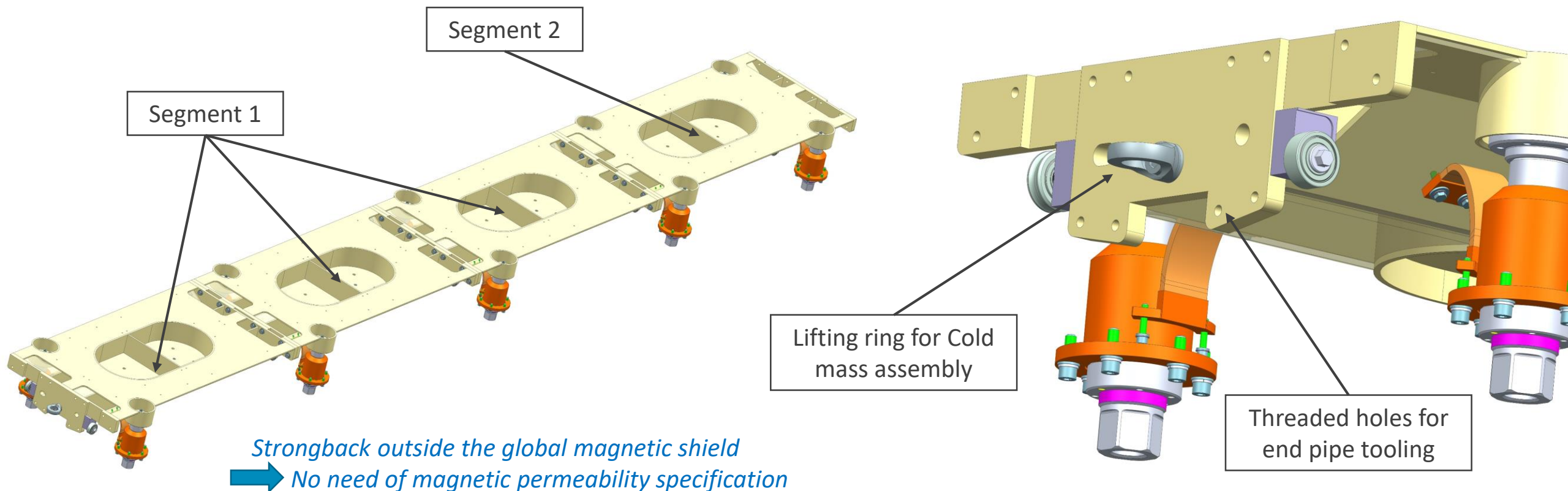


- ▶ Vacuum vessel
- ▶ **Supporting components**
 - Strongback and studs
 - G11 posts
 - Cavity post
 - C shaped element
- ▶ Helium circuitry
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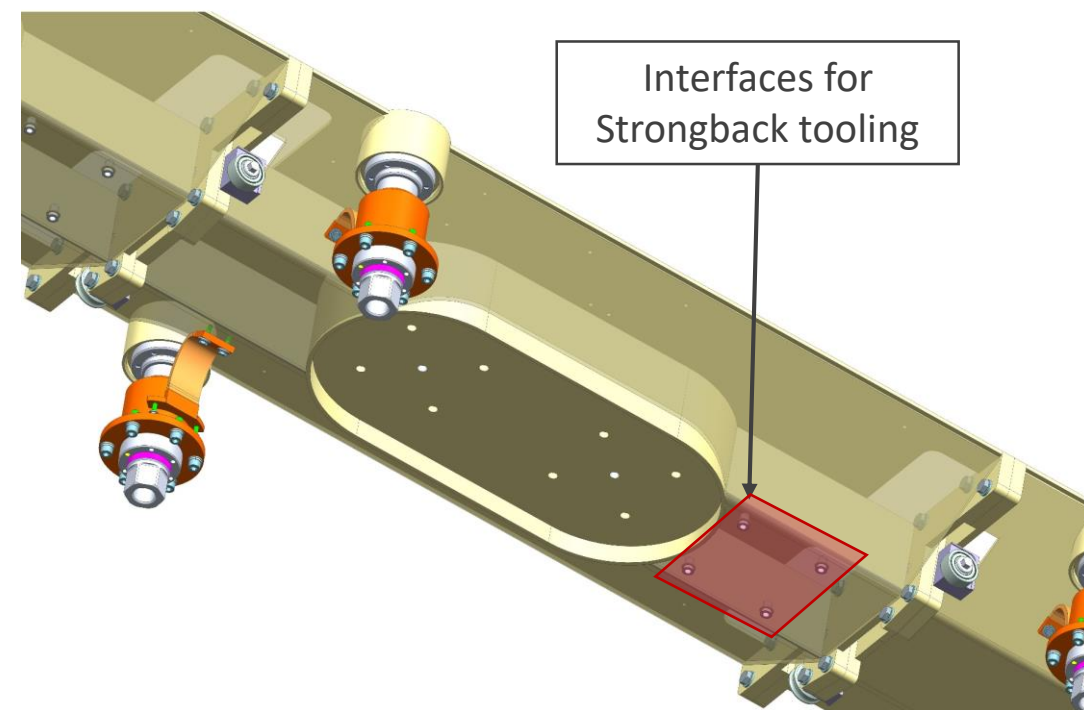
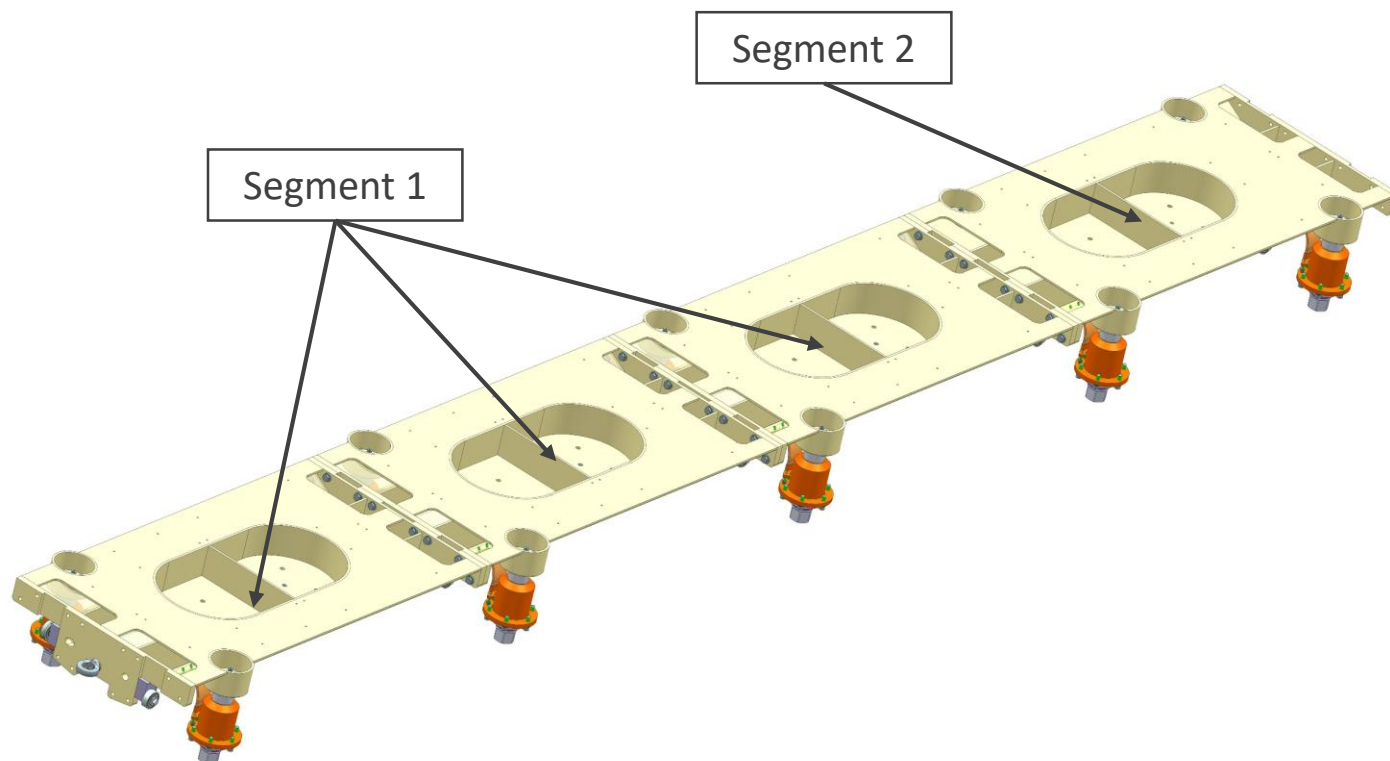
Design similar to the HB650, made of two types of segments

- ❑ Made of stainless steel 316L.
- ❑ Interface for the cold mass assembly.
- ❑ Tooling interfaces for the strongback assembly.
- ❑ Simulations for displacement, stress and screws dimensioning are on-going (taking into account the HB650 REX assembly).



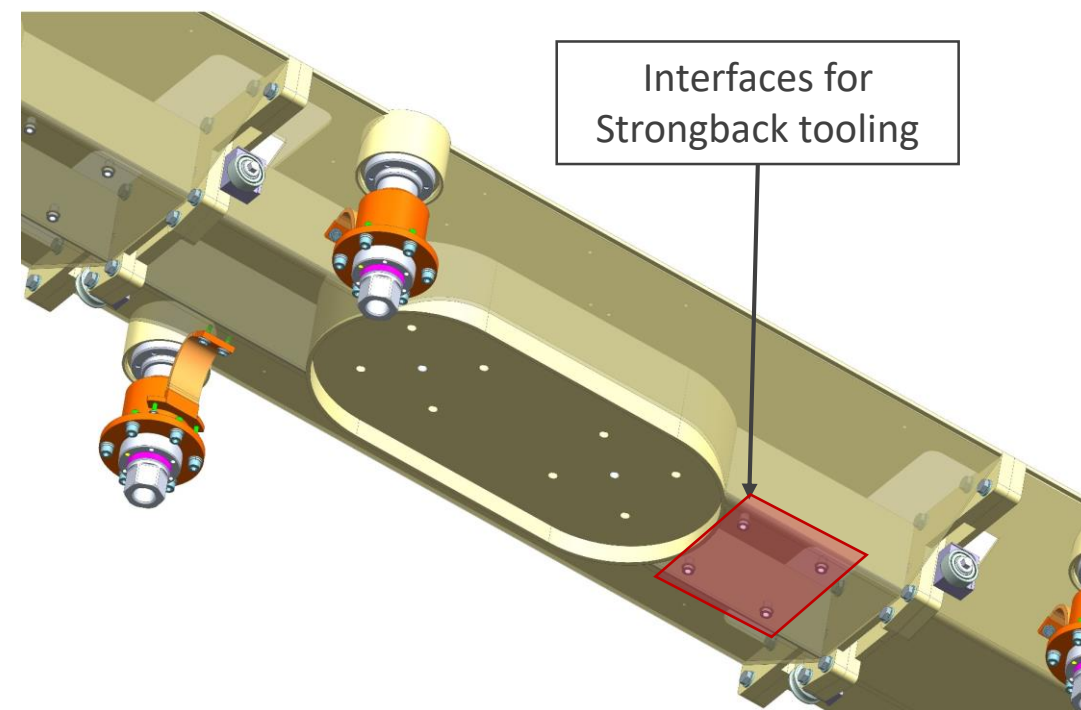
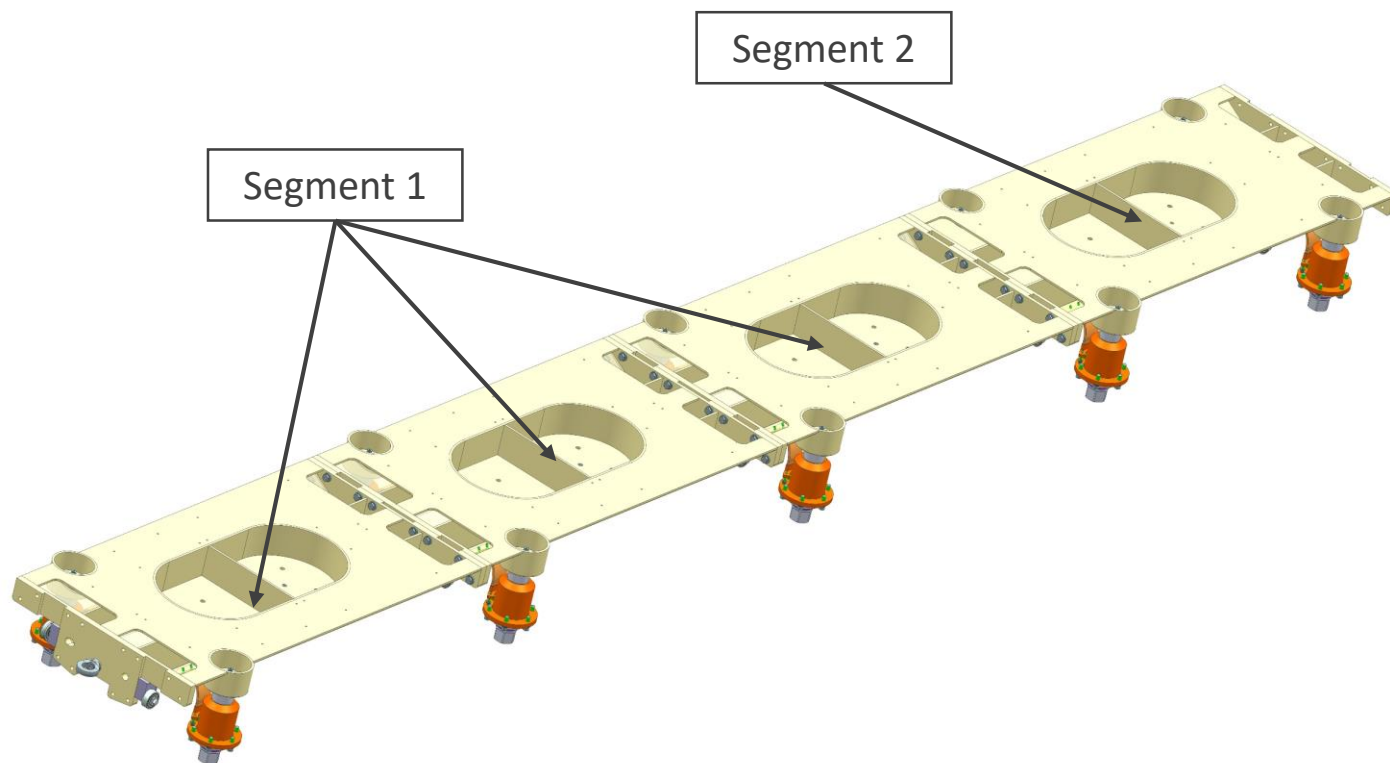
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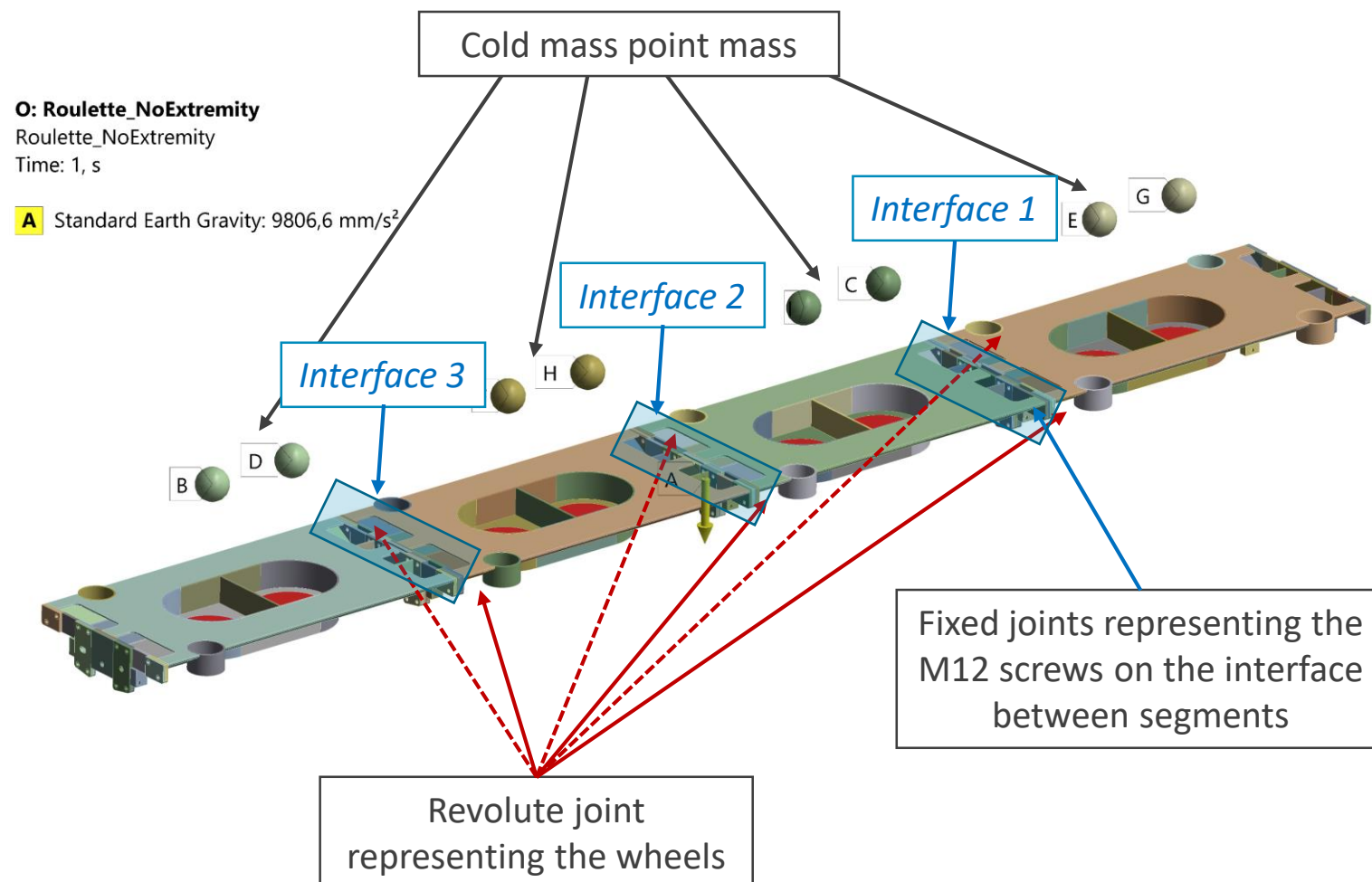
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Simulations for displacement, stress and screws dimensioning are on-going (taking into account the HB650 REX assembly).

- During the HB650 strongback assembly into the vacuum vessel, the extremity wheels were not in contact with the rails (above 5mm).
- Boundary conditions :
 - Standard earth gravity.
 - Eight point mass representing the mass of the cold mass (with a margin of 10%).
 - Revolute joint on the central wheel blocks (no wheels on the extremities).
 - 12 fixed joints representing the M12 screws on each interface between segments.

/!\ The pins between strongback segments were not taking into account /!\



Simulations for displacement, stress and screws dimensioning are on-going (taking into account the HB650 REX assembly).

□ During the HB650 strongback assembly into the vacuum vessel, the extremity wheels were not in contact with the rails (above 5mm).

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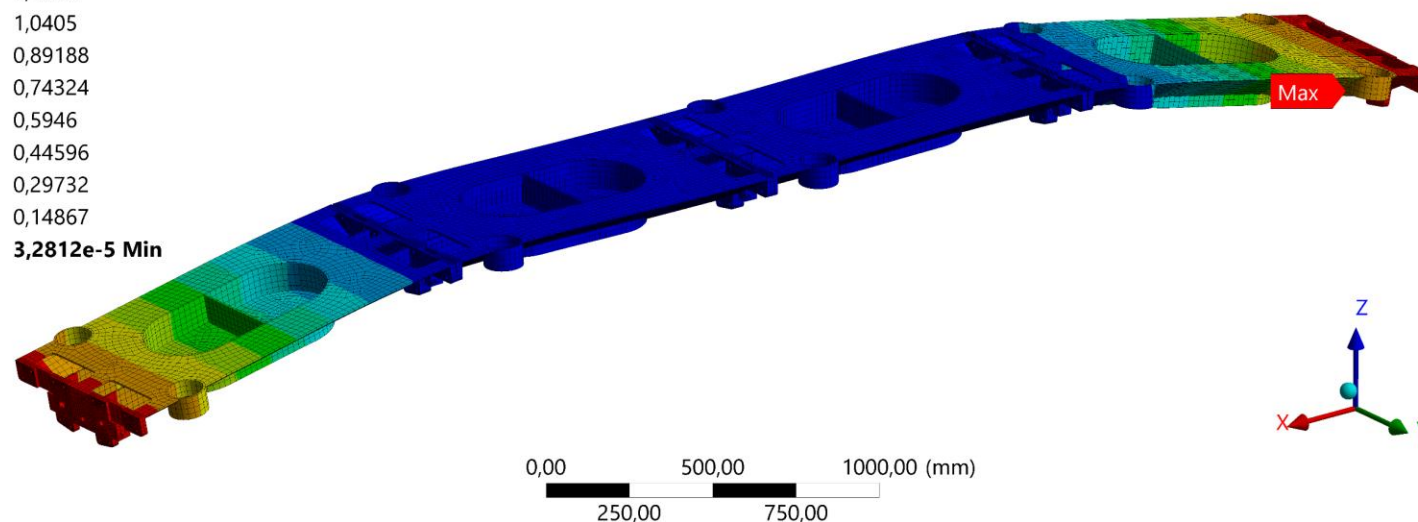
- Standard earth gravity.
- Eight point mass representing the mass of the cold mass (with a margin of 10%).
- Revolute joint on the central wheel blocks (no wheels on the extremities).
- 12 fixed joints representing the M12 screws on each interface between segments.

O: Roulette_NoExtremity
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s

1,3378 Max
1,1892
1,0405
0,89188
0,74324
0,5946
0,44596
0,29732
0,14867
3,2812e-5 Min

Strongback deformation

Max : 1.3mm



Simulations for displacement, stress and screws dimensioning are on-going (taking into account the HB650 REX assembly).

□ During the HB650 strongback assembly into the vacuum vessel, the extremity wheels were not in contact with the rails (above **5mm**).

□ Boundary conditions :

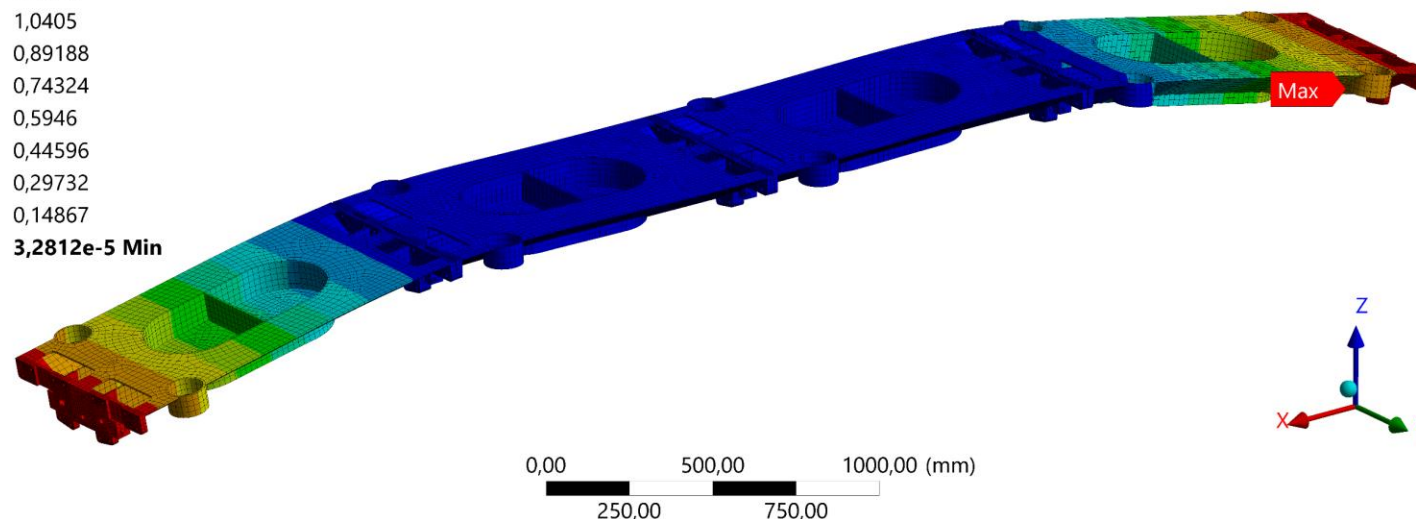
- Standard earth gravity.
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0,5946
0,44596
0,29732
0,14867
3,2812e-5 Min

Strongback deformation

Max : 1.3mm



Risk to have no contact with the wheel at extremities

Simulations for displacement, stress and screws dimensioning are on-going (taking into account the HB650 REX assembly).

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□ Boundary conditions :

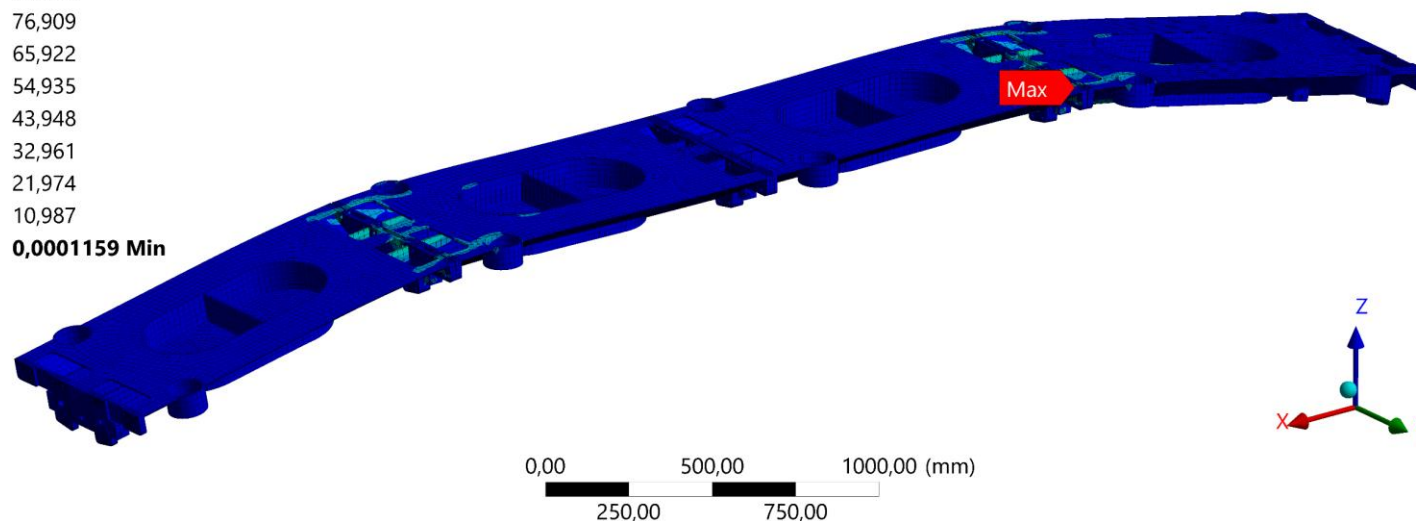
- Standard earth gravity.
- Eight point mass representing the mass of the cold mass (with a margin of 10%).
- Revolute joint on the central wheel blocks (no wheels on the extremities).
- 12 fixed joints representing the M12 screws on each interface between segments.

O: Roulette_NoExtremity
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1 s

98,883 Max
87,896
76,909
65,922
54,935
43,948
32,961
21,974
10,987
0,0001159 Min

Strongback stress

Max : 99 MPa



Simulations for displacement, stress and screws dimensioning are on-going (taking into account the HB650 REX assembly).

□ During the HB650 strongback assembly into the vacuum vessel, the extremity wheels were not in contact with the rails (above 5mm).

□ Boundary conditions :

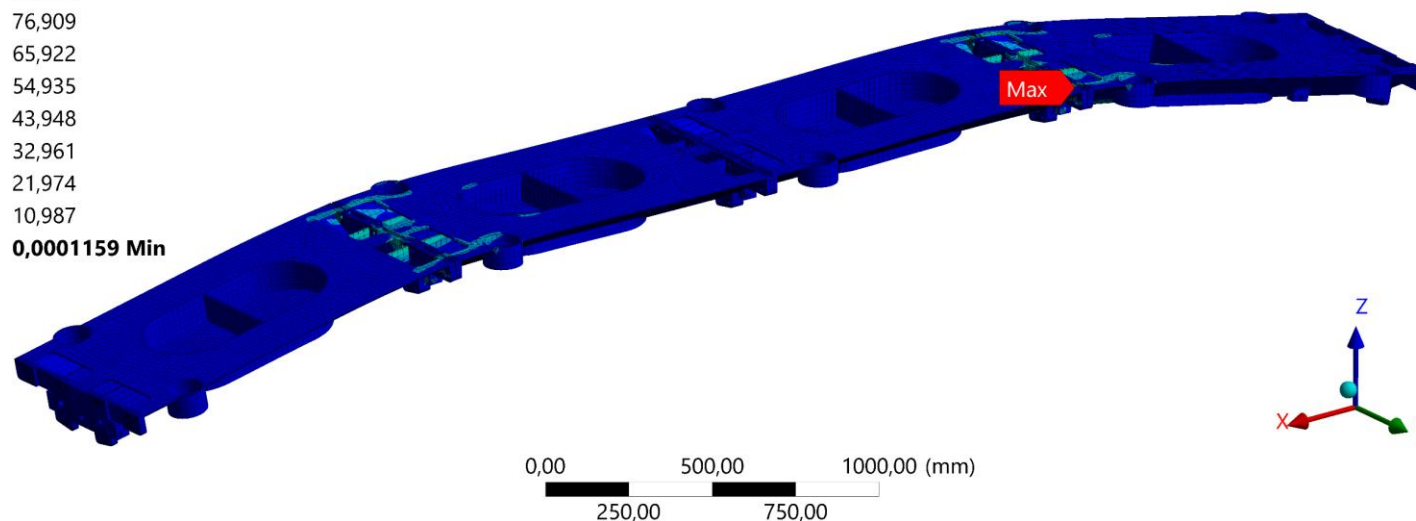
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87,896
76,909
65,922
54,935
43,948
32,961
21,974
10,987
0,0001159 Min

Strongback stress

Max : 99 MPa



Stress admissible on the 316L strongback

Simulations for displacement, stress and screws dimensioning are on-going (taking into account the HB650 REX assembly).

During the HB650 strongback assembly into the vacuum vessel, the extremity wheels were not in contact with the rails (above 5mm).

Boundary conditions :

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- Eight point mass representing the mass of the cold mass (with a margin of 10%).
- Revolute joint on the central wheel blocks (no wheels on the extremities).
- 12 fixed joints representing the M12 screws on each interface between segments.

Screw ID	Pitch	Head	d2	Transverse section	equiv d
12	1,75	16,00	10,86	84,268	10,36
class	8	7,5			

Data on the assembly	Characteristics on the assembly	Tightening
dispersion on the initial tension	precision class on the torque wrench 50 %	tightening torque in % of max torque 90 %
Friction coeff on the thread	hole D in % of nom D 103 %	max tightening torque 80,67 N.m
Friction coeff on the pieces	Hole D 13,08 mm	nom tightening torque 53,78 N.m
ratio on external force on the assembly	A coeff 2,933	max torsion torque 41,60 N.m
ratio on external force on the screw	B coeff 2,933	Aimed F0max 26,838 N
Security coeff ext force	F0max 29,887 N	F0min 17,332 N
Security coeff yield limit	F0min 19,925 N	max variation due to thermal cte mismatch 0 N
Security coeff ultimate limit	nom torque 53,75 N.m	norme NF E 25-030-1 108% yield limit 26,838 N
	max torque 46,23 N.m	F0min th corrected 17,332 N

note: aimed F0max (N12) will be obtained at a nominal tightening torque (N10) with adjusted torque wrench

Elem ID	X Coord mm	Y Coord mm	Z Coord mm	F _n N	F _{shear} N	M _{bending} N.m	tensile stress σ0 MPa	shear stress MPa	VM stress MPa	slide	gap	yield	ultimate
Interfac_1_1				-5836,71	118,32	34,70	365,95	190,65	432,91	11,52	0,52	0,11	0,08
Interfac_1_2				-77,29	1133,44	1,76	319,82	190,65	453,70	1,33	58,30	0,19	0,16
Interfac_1_3				131,00	493,52	2,78	320,25	190,65	460,00	4,33	35,63	0,19	0,16
Interfac_1_4				-2317,72	1116,64	15,66	342,57	190,65	475,81	0,86	2,15	0,15	0,12
Interfac_1_5				-5230,04	940,09	8,89	361,09	190,65	489,31	0,71	1,22	0,11	0,09
Interfac_1_6				113,21	474,69	2,83	320,11	190,65	459,30	4,55	37,08	0,19	0,16
Interfac_1_7				12,29	1130,45	1,89	319,30	190,65	459,34	1,35	85,90	0,19	0,16
Interfac_1_8				-5162,16	854,85	3,59	360,55	190,65	488,91	0,90	1,23	0,12	0,09
Interfac_1_9				-3051,69	985,32	15,72	343,64	190,65	476,58	1,08	2,05	0,14	0,12
Interfac_1_10				-5685,75	372,25	30,93	364,74	190,65	492,01	3,08	0,61	0,11	0,08
Interfac_1_11				-5613,24	127,64	33,46	364,16	190,65	491,58	11,02	0,58	0,11	0,08
Interfac_1_12				-5769,84	327,83	30,12	365,42	190,65	492,51	3,58	0,60	0,11	0,08
Interfac_2_1				-533,43	25,93	2,71	323,47	190,65	462,25	97,33	16,50	0,18	0,15
Interfac_2_2				-1532,66	63,58	9,89	331,48	190,65	467,88	35,96	4,64	0,17	0,14
Interfac_2_3				-1219,10	49,55	3,05	328,96	190,65	466,11	47,70	5,73	0,17	0,14
Interfac_2_4				-658,42	68,50	4,50	324,47	190,65	462,95	35,86	11,85	0,18	0,15
Interfac_2_5				-560,79	20,08	4,29	323,69	190,65	462,40	125,70	13,47	0,18	0,15
Interfac_2_6				-563,79	38,59	3,20	323,71	190,65	462,42	64,92	15,00	0,18	0,15
Interfac_2_7				33	190,65	462,15	33	190,65	462,15	95,98	17,26	0,18	0,15
Interfac_2_8				94	190,65	462,57	94	190,65	462,57	34,73	14,63	0,18	0,15
Interfac_2_9				92	190,65	462,57	92	190,65	462,57	161,49	12,73	0,18	0,15
Interfac_2_10				55	190,65	463,00	55	190,65	463,00	28,18	11,78	0,18	0,15
Interfac_2_11				64	190,65	466,52	64	190,65	466,52	79,54	5,39	0,17	0,14
Interfac_2_12				64	190,65	468,00	64	190,65	468,00	43,07	4,51	0,17	0,14
Interfac_3_1				87	190,65	490,62	87	190,65	490,62	17,55	0,61	0,11	0,09
Interfac_3_2				14	190,65	461,32	14	190,65	461,32	8,15	17,49	0,18	0,16
Interfac_3_3				65	190,65	460,28	65	190,65	460,28	2,50	27,68	0,19	0,16
Interfac_3_4				-5759,91	1562,40	7,21	365,34	224,02	532,94	-0,04	1,09	0,02	0,00
Interfac_3_5				-2643,43	1024,47	14,38	340,37	190,65	474,23	1,08	2,46	0,15	0,12
Interfac_3_6				-5294,36	300,10	30,64	361,61	190,65	489,69	4,32	0,69	0,11	0,09
Interfac_3_7				-5266,53	118,26	32,69	361,38	190,65	489,53	12,56	0,66	0,11	0,09
Interfac_3_8				-5376,57	311,70	30,21	362,27	190,65	490,18	4,07	0,68	0,11	0,09
Interfac_3_9				-2845,09	940,40	15,02	341,99	190,65	475,39	1,22	2,24	0,15	0,12
Interfac_3_10				-5739,67	1446,94	7,87	365,17	190,65	492,33	0,04	1,08	0,11	0,08
Interfac_3_11				236,98	1089,30	3,27	321,10	190,65	460,59	1,40	25,09	0,18	0,16
Interfac_3_12				385,67	372,16	4,22	322,29	190,65	461,42	5,93	17,01	0,18	0,16

Sliding on one screw.
Enough margin on the 11 other screws on this interface

Simulations for displacement, stress and screws dimensioning are on-going (taking into account the HB650 REX assembly).

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class	8	7,5			

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dispersion on the initial tension	precision class on the torque wrench 50 %	tightening torque in % of max torque 90 %
Friction coeff on the thread	hole D in % of nom D 103 %	max tightening torque 80,67 N.m
Friction coeff on the pieces	Hole D 13,08 mm	nom tightening torque 53,78 N.m
ratio on external force on the assembly	A coeff 2,933	max torsion torque 41,60 N.m
ratio on external force on the screw	B coeff 2,933	Aimed F0max 26,838 N
Security coeff ext force	max torque 89,628 N.m	F0min 17,332 N
Security coeff yield limit	F0max 29,887 N	max variation due to thermal cte mismatch 0 N
Security coeff ultimate limit	F0min 19,925 N	max F0max th corrected 26,838 N
	nom torque 53,75 N.m	F0min th corrected 17,332 N
	max torque 46,23 N.m	

note: aimed F0max (N12) will be obtained at a nominal tightening torque (N10) with adjusted torque wrench

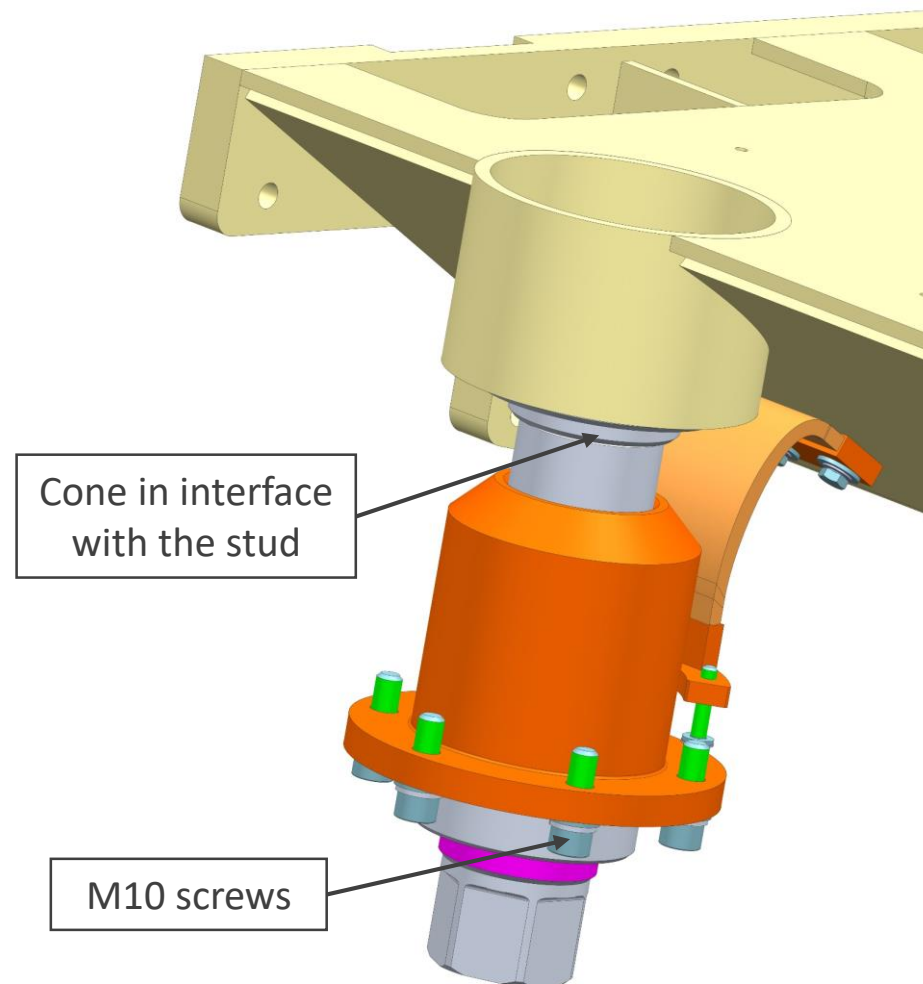
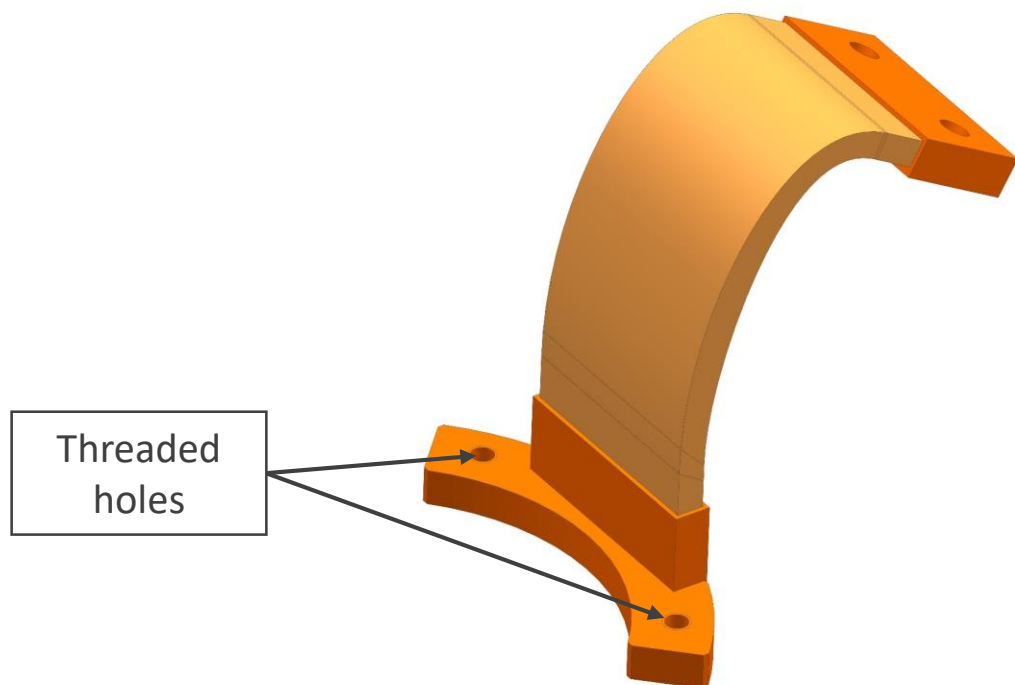
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Interfac_1_2				-77,29	1133,44	1,76	319,82	190,65	459,70	1,33	58,30	0,19	0,16
Interfac_1_3				131,00	493,52	2,78	320,25	190,65	460,00	4,33	35,63	0,19	0,16
Interfac_1_4				-2317,72	1116,64	15,66	342,57	190,65	475,81	0,86	2,15	0,15	0,12
Interfac_1_5				-5230,04	940,09	8,89	361,09	190,65	489,31	0,71	1,22	0,11	0,09
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Interfac_1_9				-3051,69	985,32	15,72	343,64	190,65	476,58	1,08	2,05	0,14	0,12
Interfac_1_10				-5685,75	372,25	30,33	364,74	190,65	492,01	3,08	0,61	0,11	0,08
Interfac_1_11				-5613,24	127,64	33,46	364,16	190,65	491,58	11,02	0,58	0,11	0,08
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Interfac_2_8				94	190,65	462,57	94	190,65	462,57	34,73	14,63	0,18	0,15
Interfac_2_9				92	190,65	462,57	92	190,65	462,57	161,49	12,73	0,18	0,15
Interfac_2_10				55	190,65	463,00	55	190,65	463,00	28,18	11,78	0,18	0,15
Interfac_2_11				64	190,65	466,52	64	190,65	466,52	79,54	5,39	0,17	0,14
Interfac_2_12				64	190,65	468,00	64	190,65	468,00	43,07	4,51	0,17	0,14
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Sliding on one screw.
Enough margin on the 11 other screws on this interface

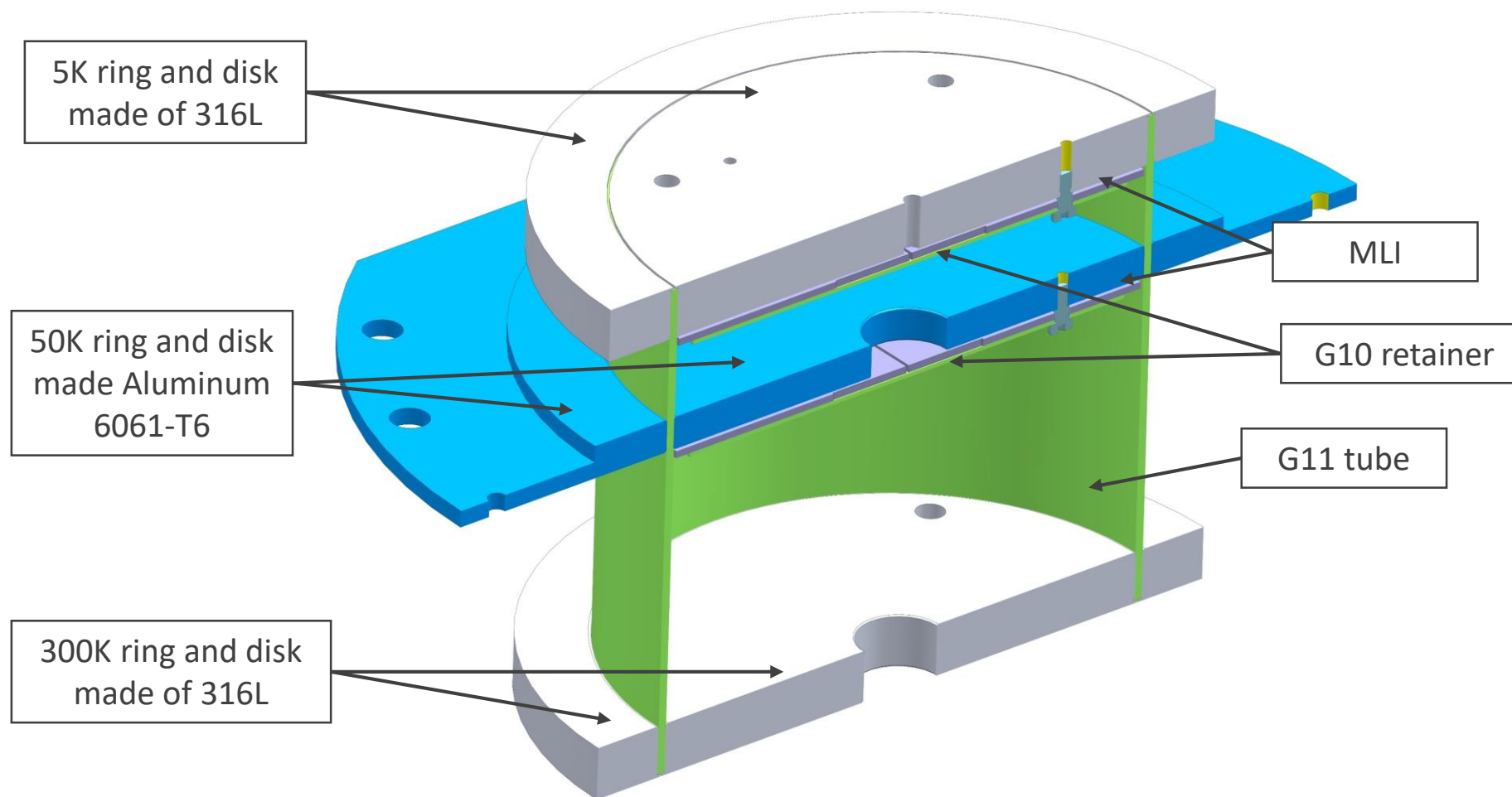
Enough margin on the other 11 screws at this interface. Moreover, the pins were not taking into account in this simulations.

Studs design similar to the HB650

- ❑ More play for the studs assembly on vacuum vessel.
- ❑ More play for the cone assembly on the strongback.
- ❑ M10 screws for the vacuum vessel assembly.
- ❑ Thermal braids on strongback have threaded holes in order to ease their assembly.

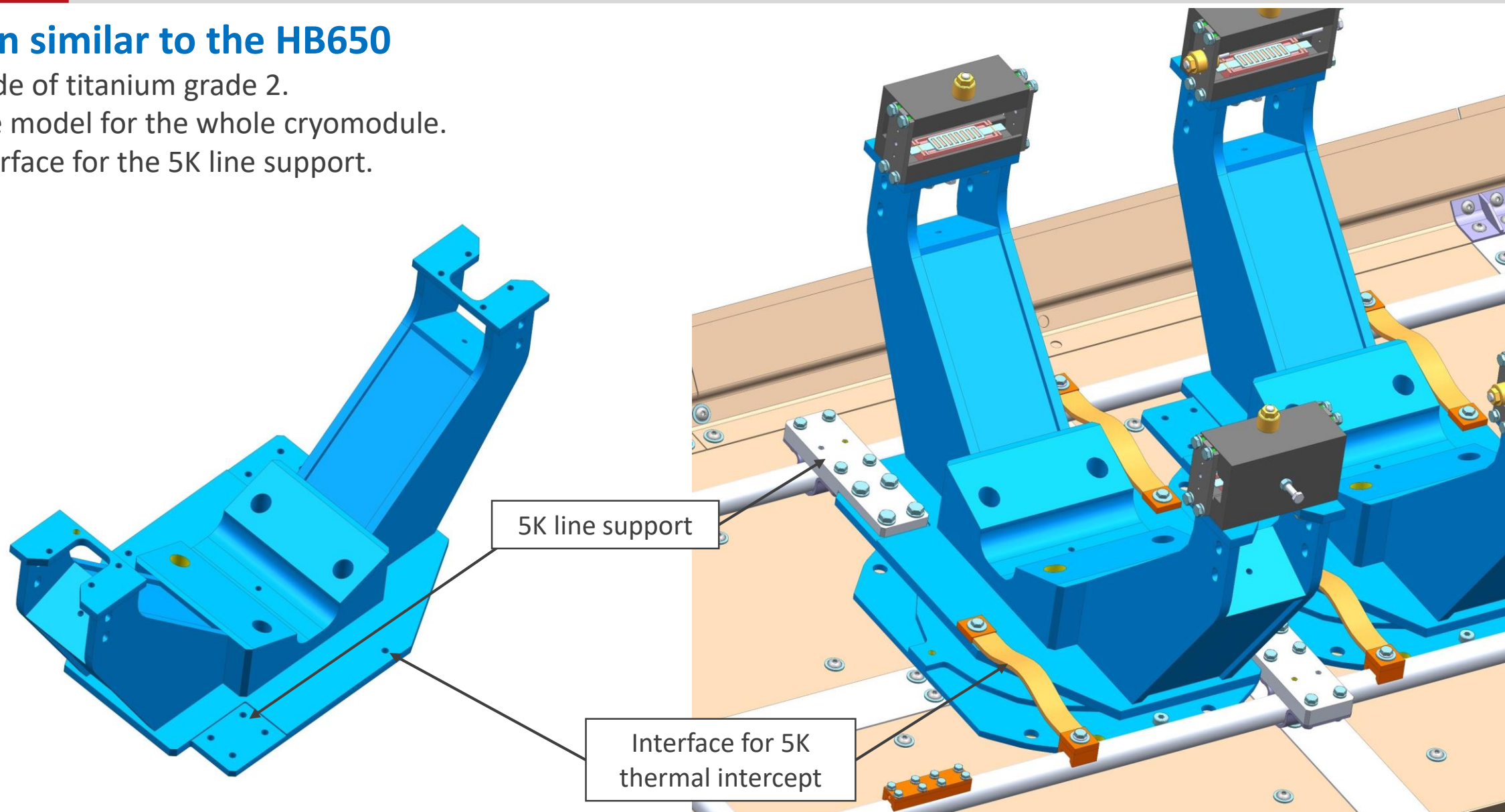


Identical to the HB650 design



Design similar to the HB650

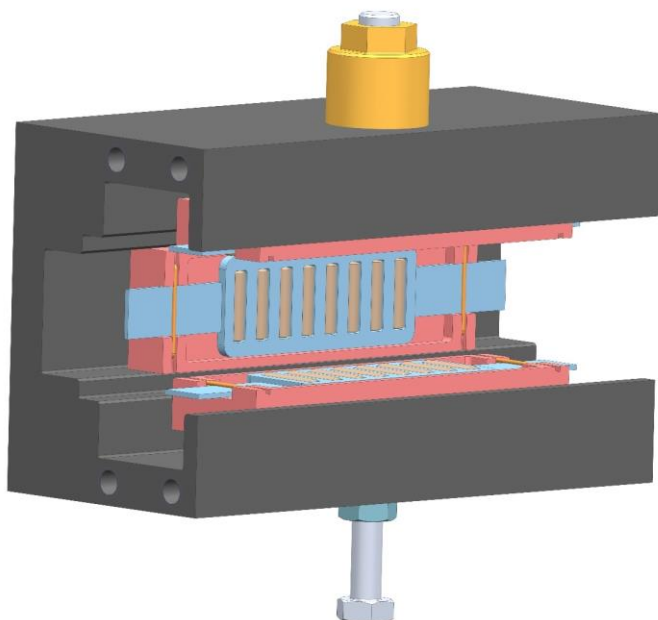
- ❑ Made of titanium grade 2.
- ❑ One model for the whole cryomodule.
- ❑ Interface for the 5K line support.



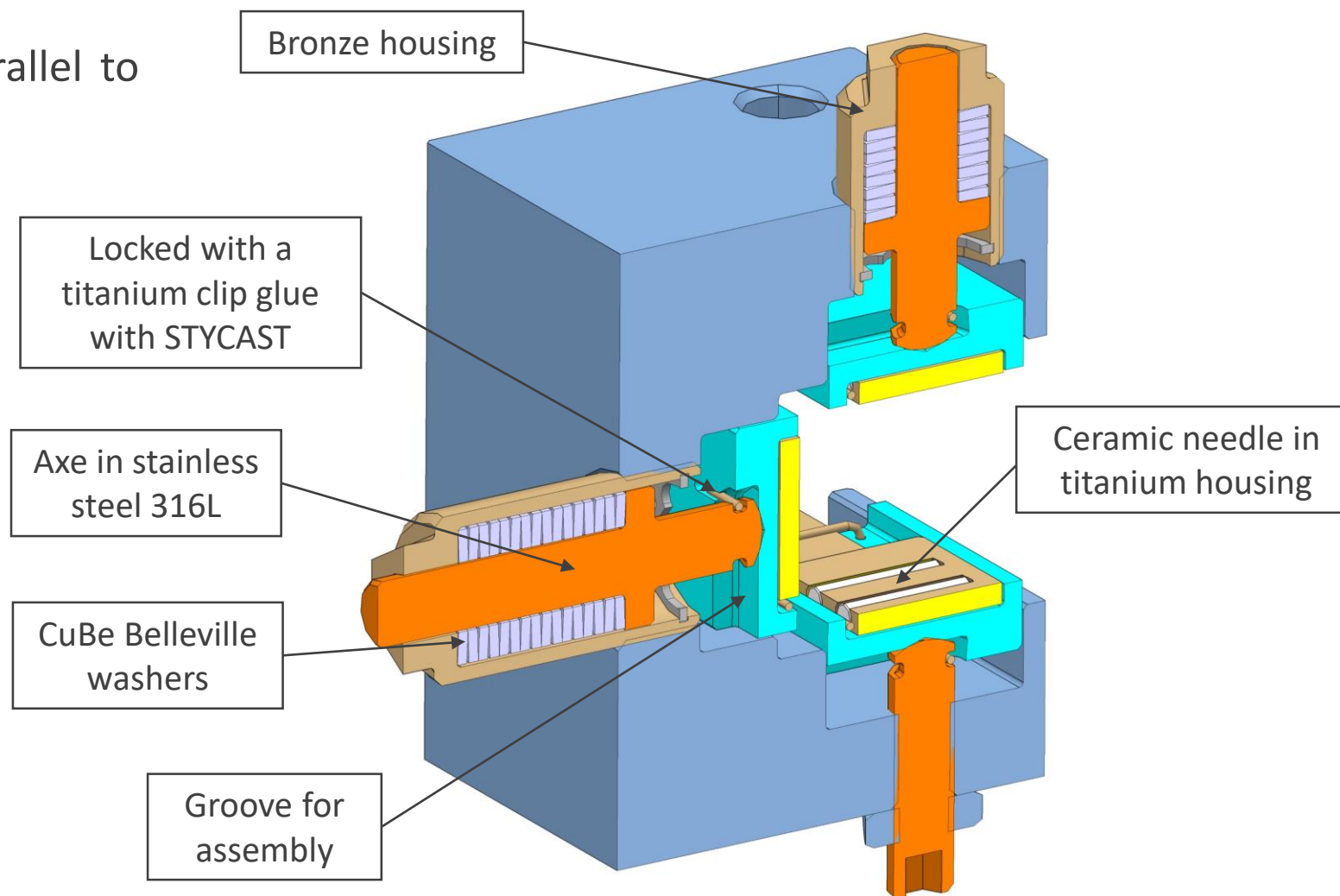
Small modifications of the HB650 design

- ❑ Limitation of the use of Stainless steel for magnetic hygiene.
- ❑ Completely assembled on a table in parallel to the cryomodule assembly.

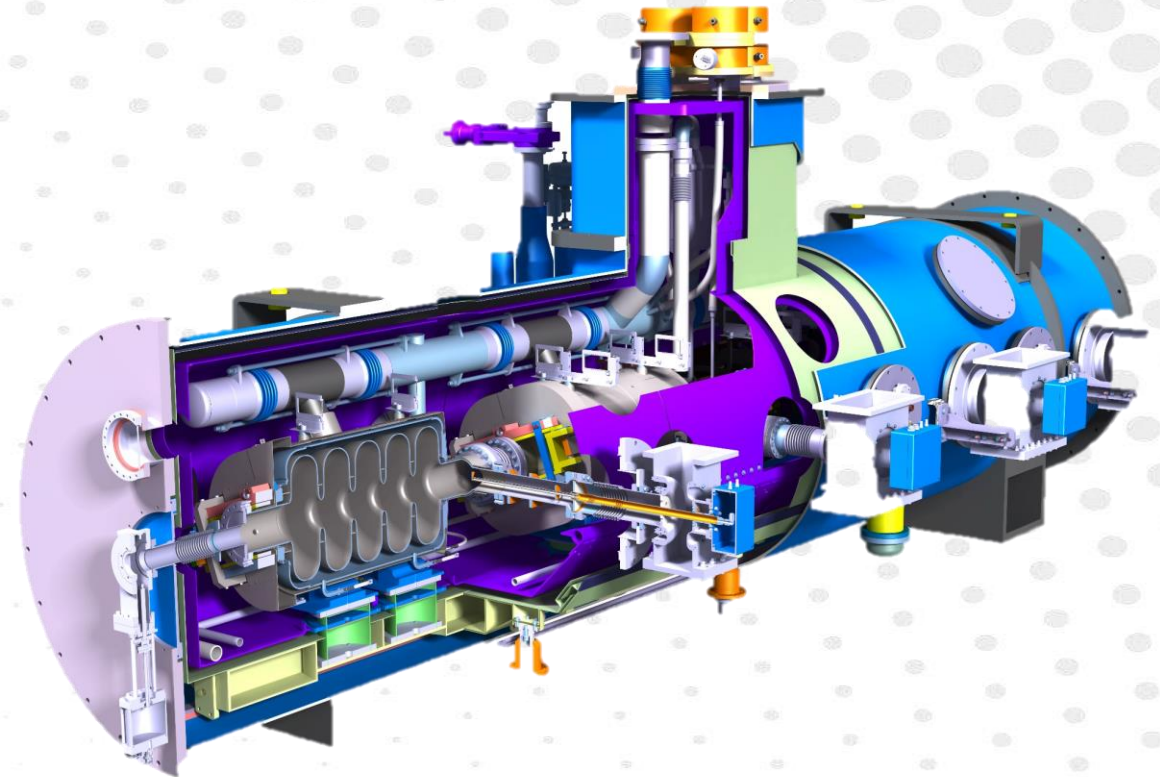
FNAL C shaped element



Proposed design

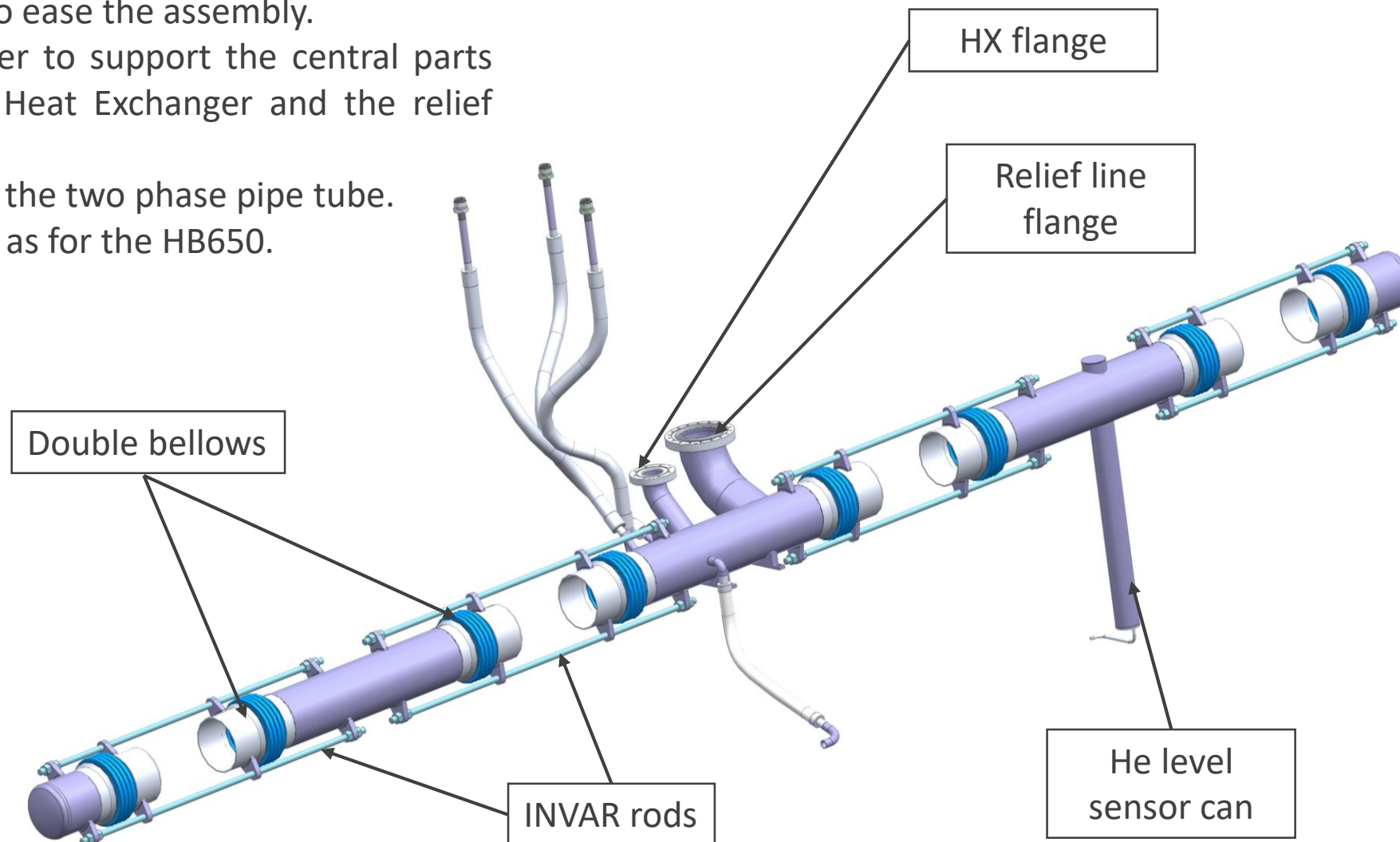


- ▶ Vacuum vessel
- ▶ Supporting components
 - Strongback and studs
 - G11 posts
 - Cavity post
 - C shaped element
- ▶ Helium circuitry
 - Two phase pipe
 - 5K circuitry
 - Cooling down circuitry
 - Relief line
- ▶ End pipe tube
- ▶ Thermal shield
- ▶ Magnetic shield
 - Global warm magnetic shield
 - Local cold magnetic shield



Two phase pipe design

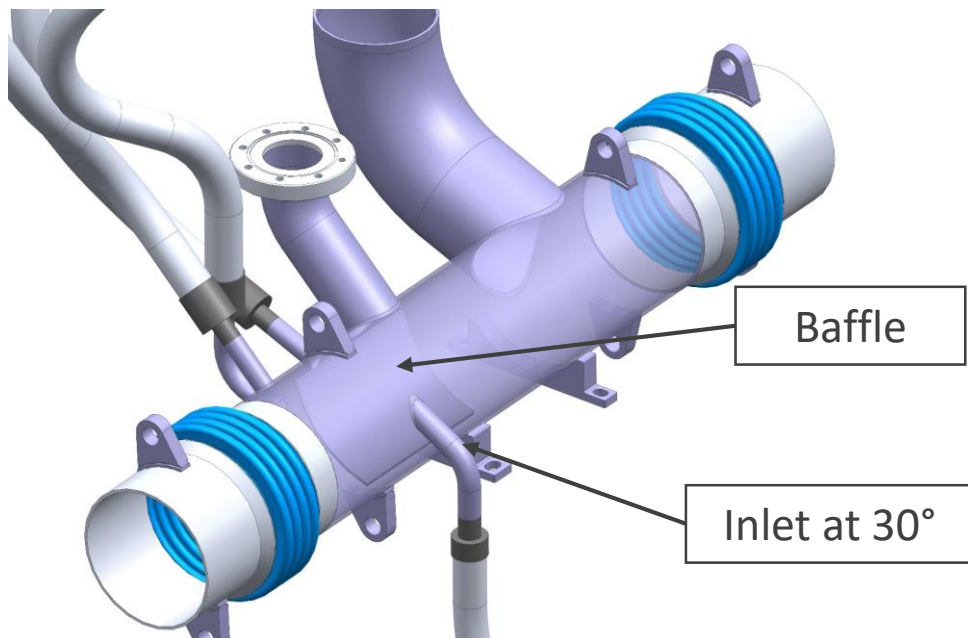
- ❑ Double bellows in order to ease the assembly.
- ❑ G11 support used in order to support the central parts (with the weight of the Heat Exchanger and the relief line).
- ❑ Inlet on the upper part of the two phase pipe tube.
- ❑ A baffle have been added as for the HB650.



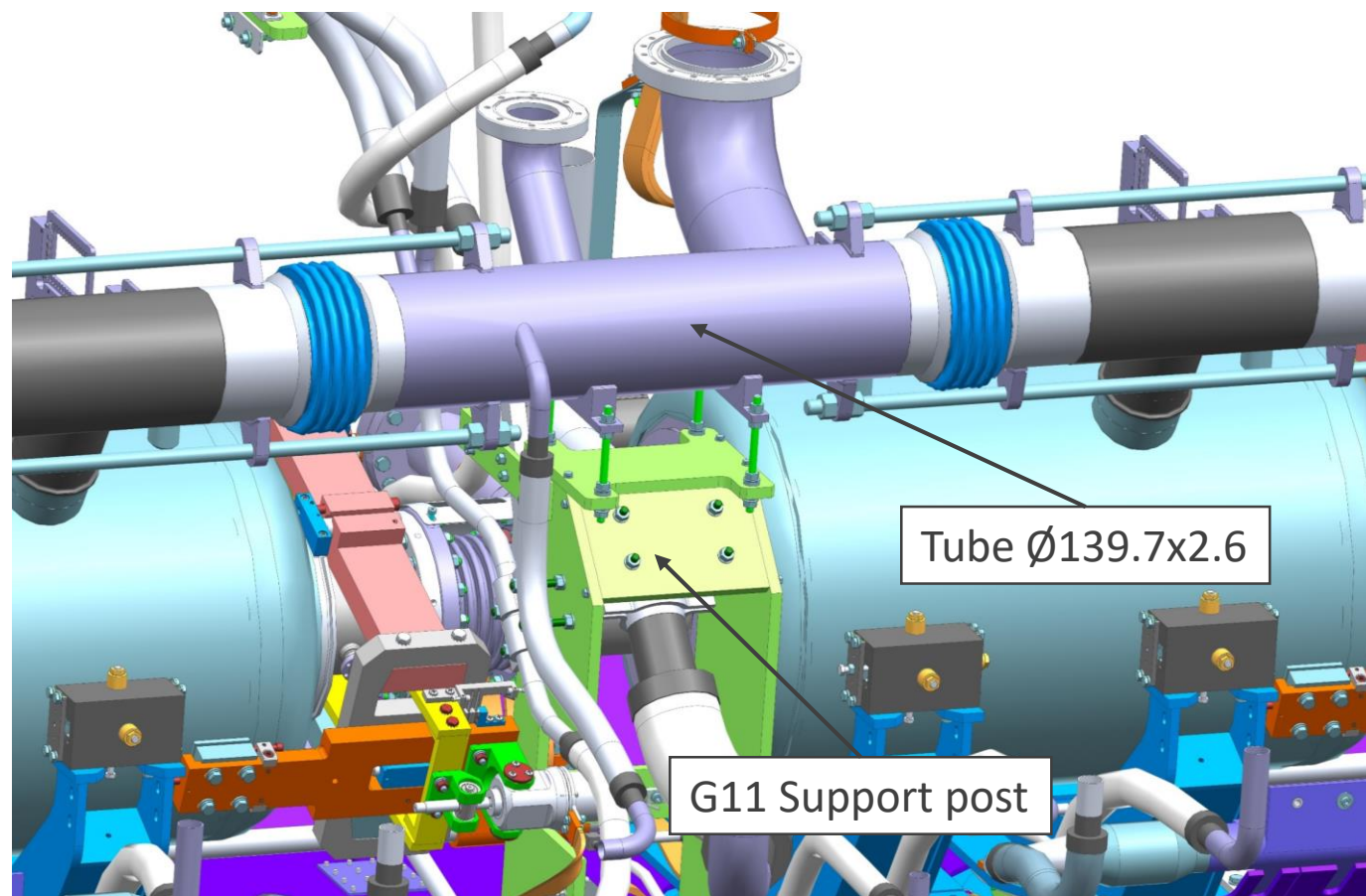
Two phase pipe design

- ❑ Double bellows in order to ease the assembly.
- ❑ G11 support used in order to support the central parts (with the weight of the Heat Exchanger and the relief line).
- ❑ Inlet on the upper part of the two phase pipe tube.
- ❑ A baffle have been added as for the HB650.

Central part of the two phase pipe

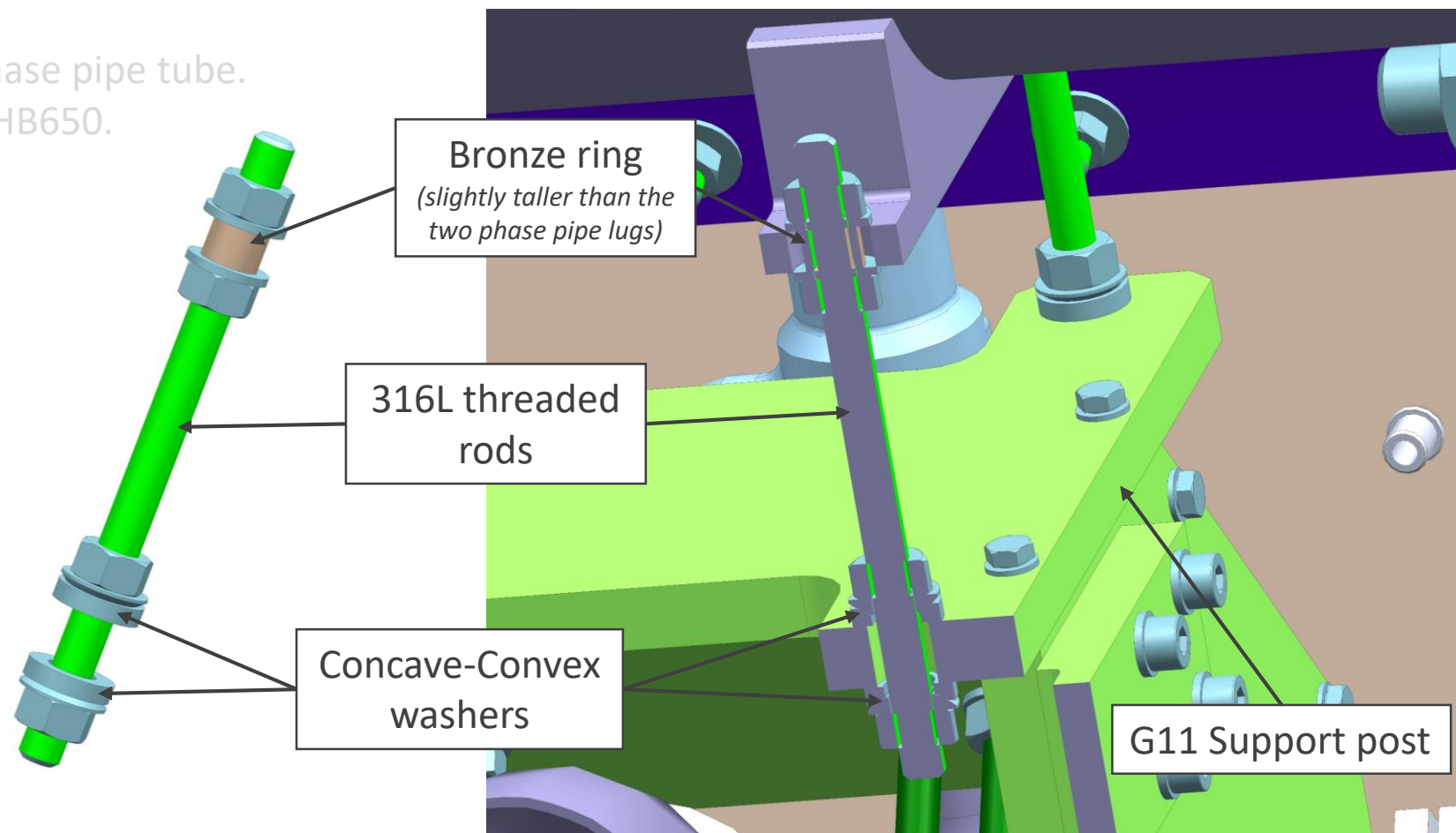
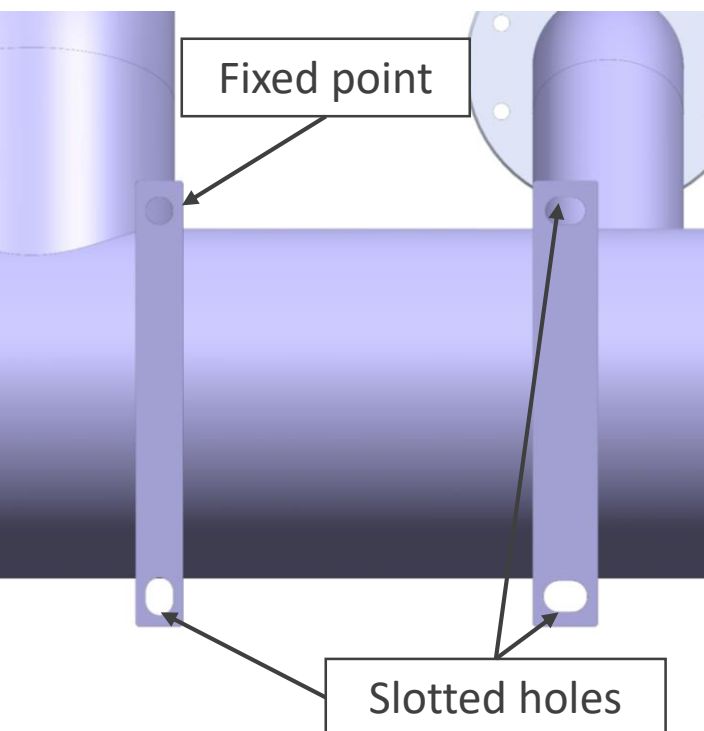


Central part of the two phase pipe supported by G11 post (Slotted holes and bronze ring used for thermal shrinkage)



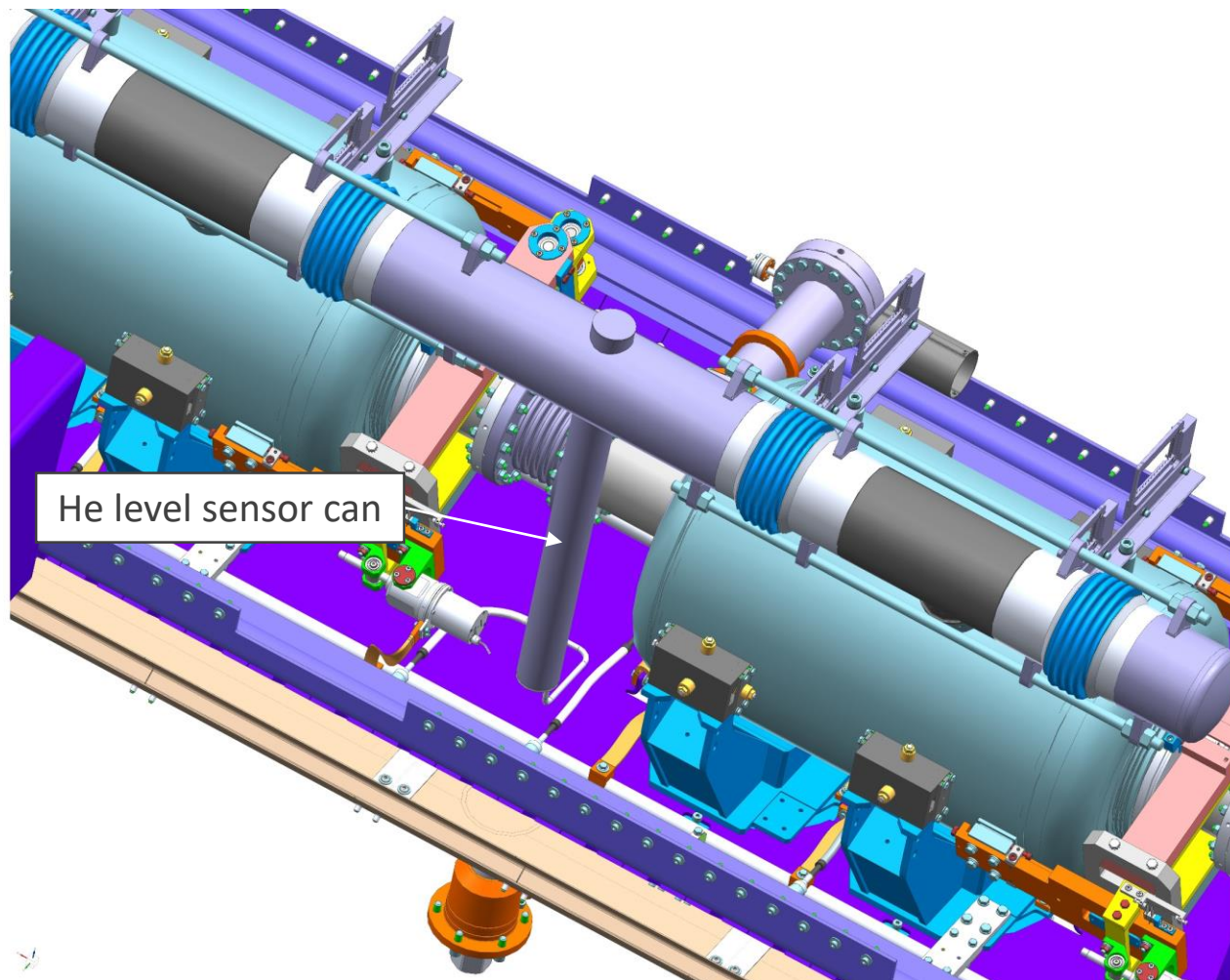
Two phase pipe design

- ❑ Double bellows in order to ease the assembly.
- ❑ G11 support used in order to support the central parts (with the weight of the Heat Exchanger and the relief line).
- ❑ Inlet on the upper part of the two phase pipe tube.
- ❑ A baffle have been added as for the HB650.



He Level sensor

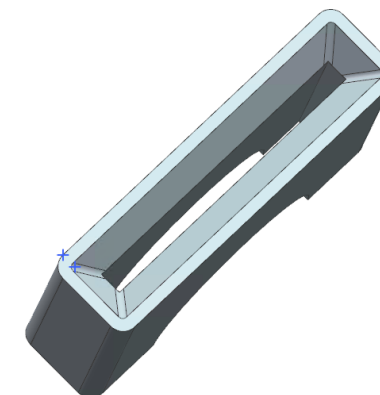
- ❑ Height compared to the two phase pipe center identical to the HB650.
- ❑ Guide on the bottom part of the He level sensor can similar to the HB650.



*Bottom part of
the He level
sensor*

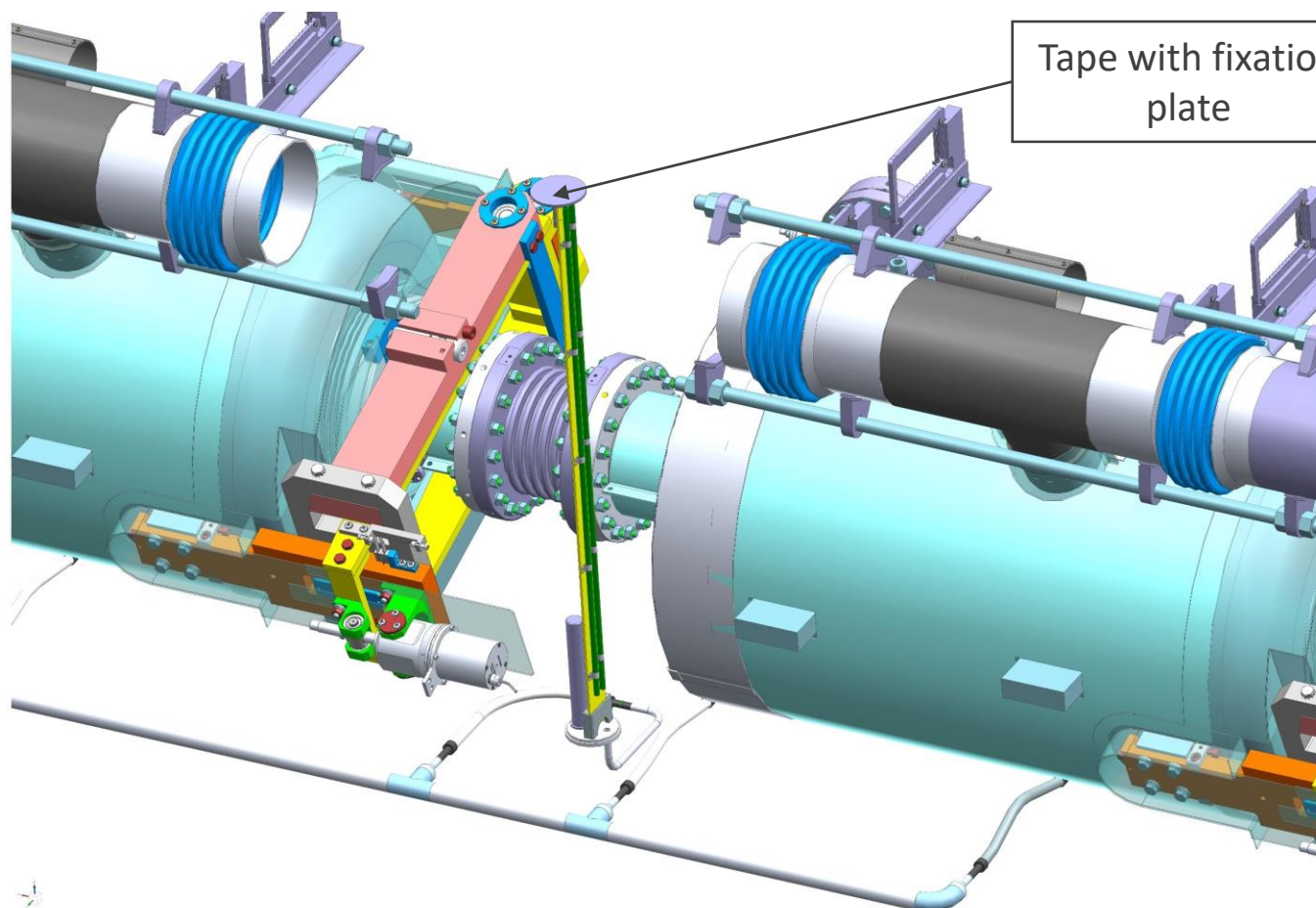


*Guided for G10
He level sensor*



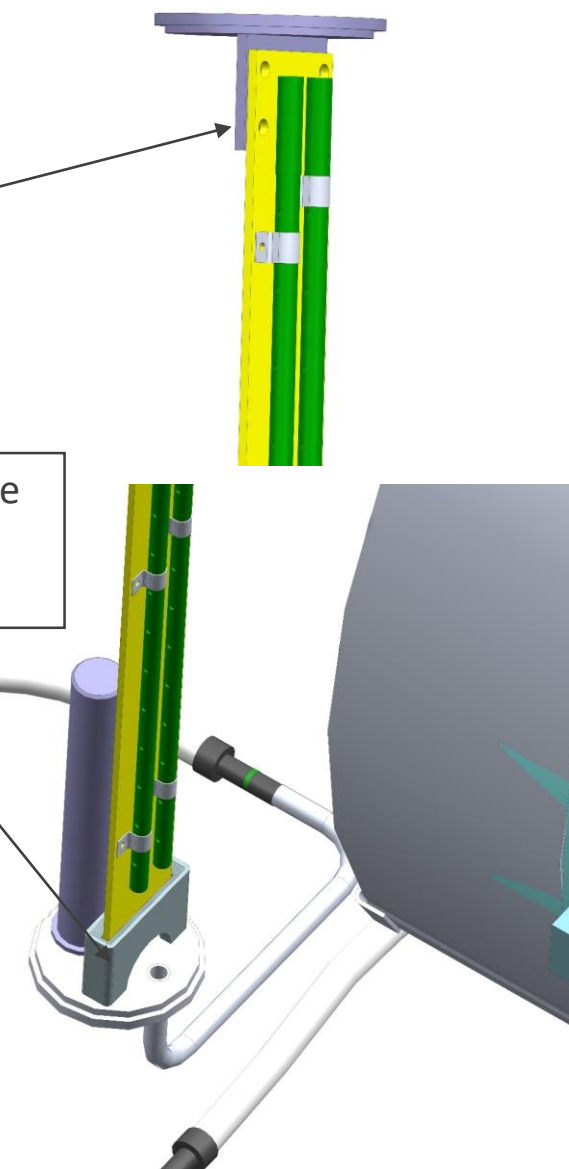
He Level sensor

- ❑ Height compared to the two phase pipe center identical to the HB650.
- ❑ Guide on the bottom part of the He level sensor can similar to the HB650.



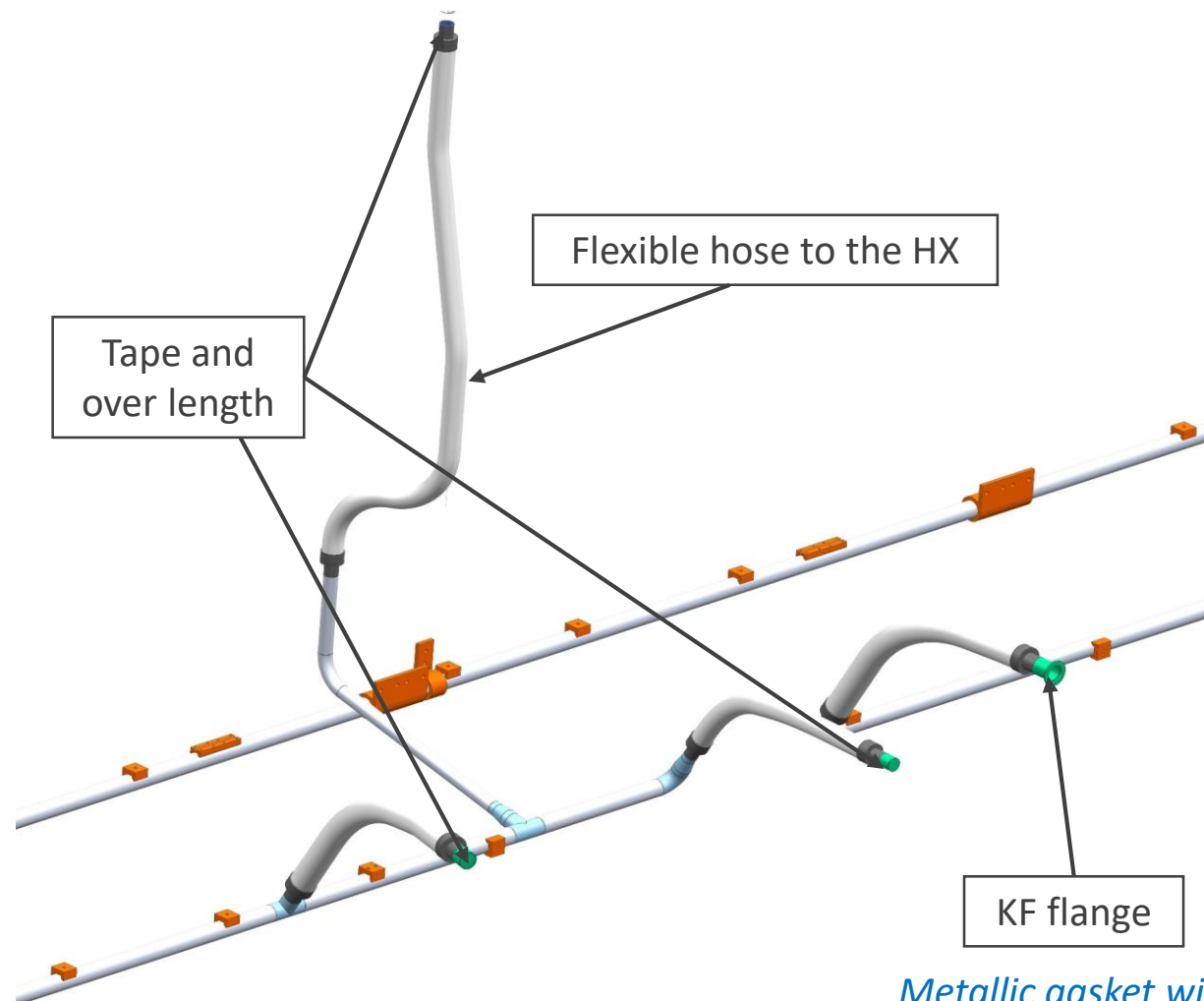
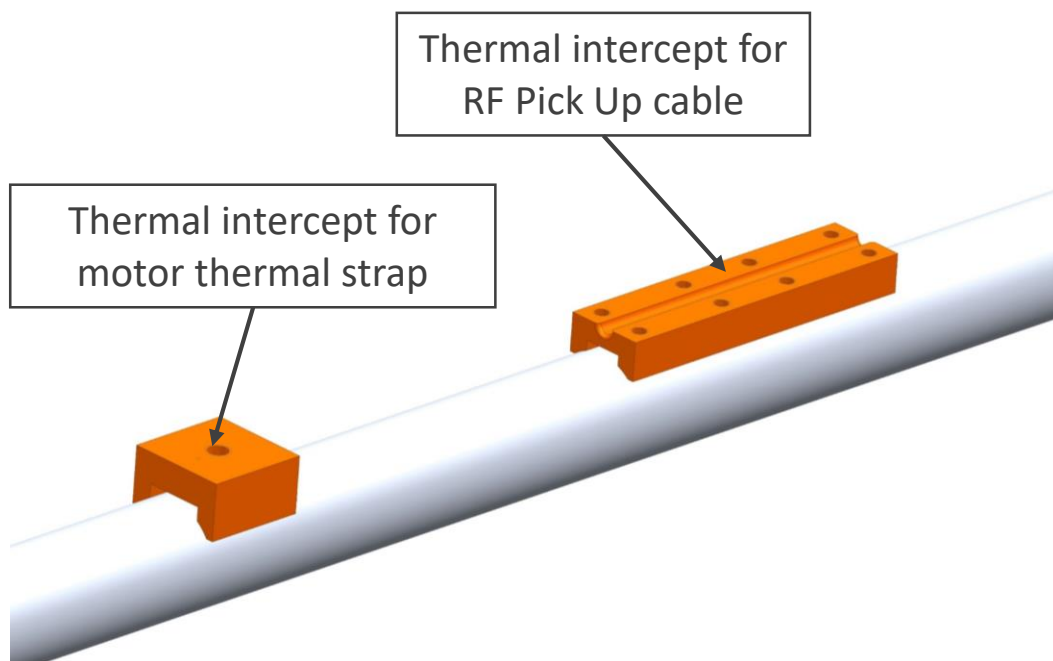
Tape with fixation
plate

Guide welded on the
bottom part.
Play of 0.25mm



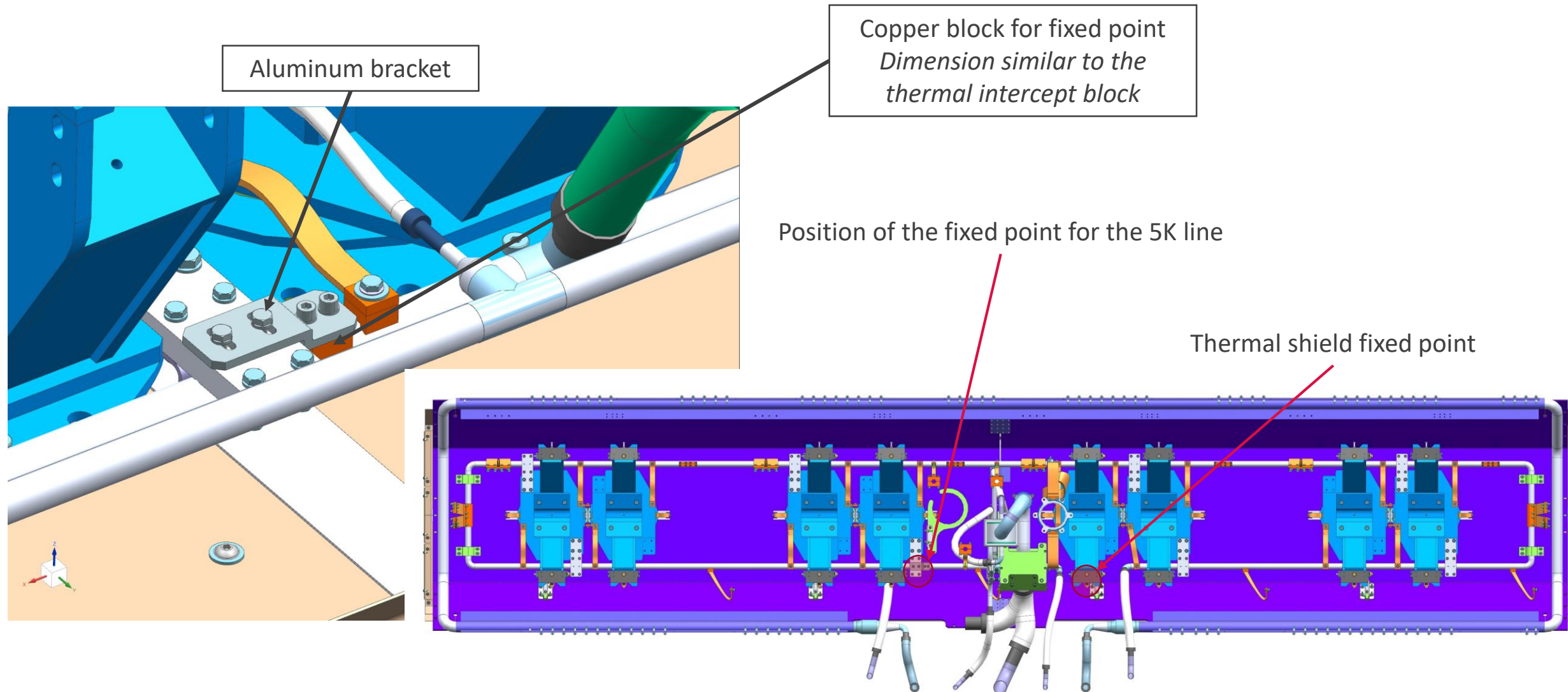
5K line design

- ❑ Thermal intercept made of brazed copper block.
- ❑ Tube with the flexible hose to the HX will be welded by the manufacturer. Thus the tube is under the beam axis for assembly purpose.
- ❑ Configuration with tape and KF flange for leak test at reception at CEA.



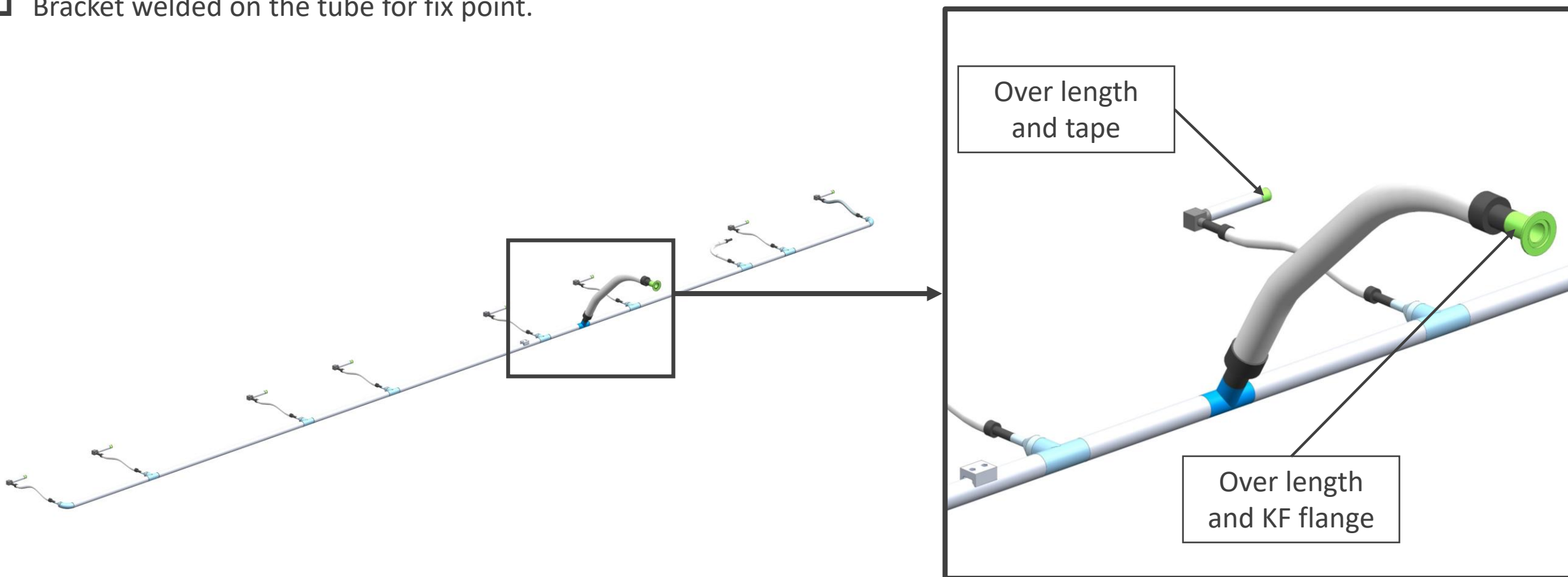
Metallic gasket will be used for the leak test

Fixed point for thermal shrinkage - 5K line



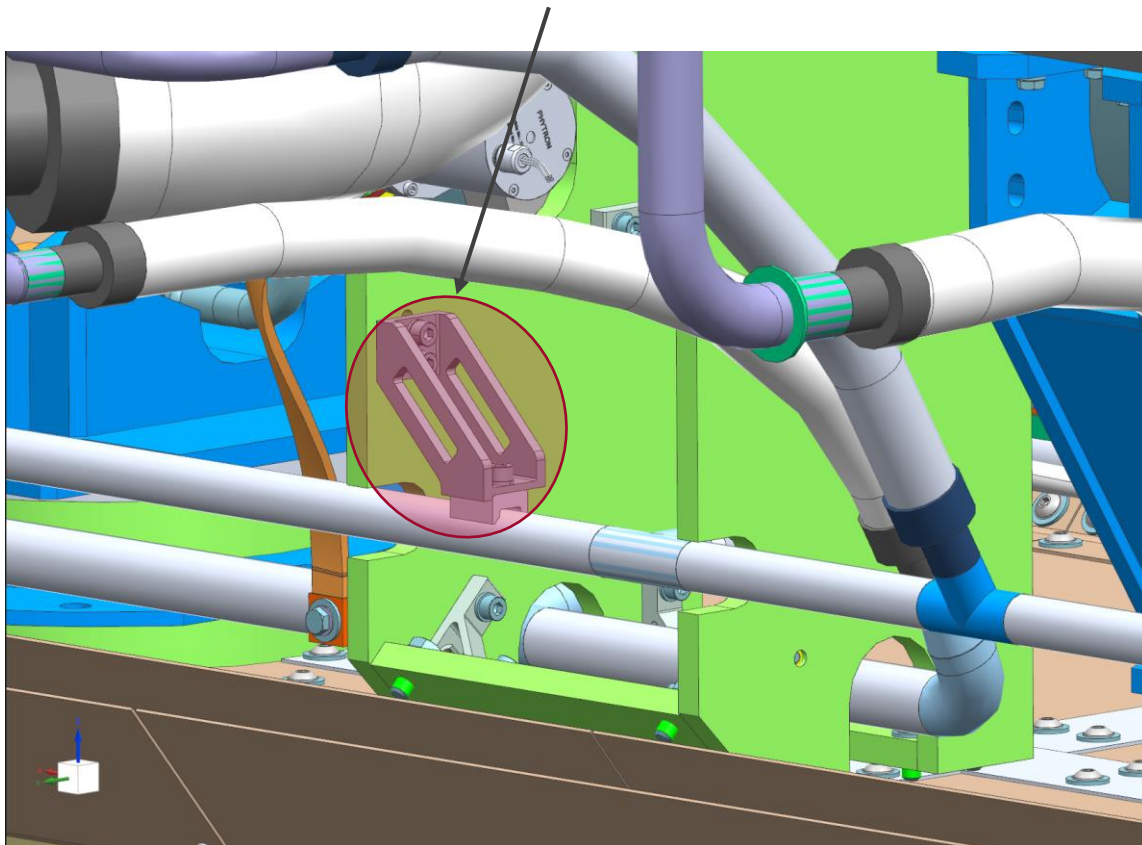
Cooling down line design

- ❑ Configuration with tape and KF flange for leak test at reception at CEA.
- ❑ Bracket welded on the tube for fix point.



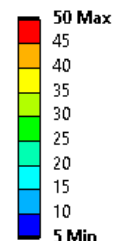
Fixe point for thermal shrinkage – Cooling down line

G11 Bracket on contact between G11 support and the Cooling down line

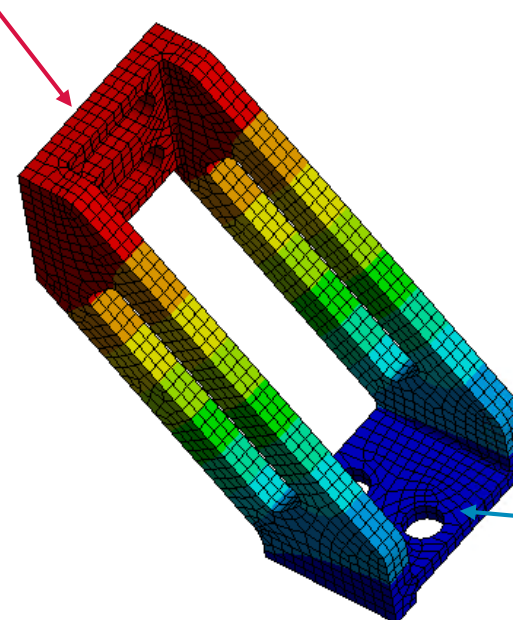


2mW of thermal loss between 5K et 50K

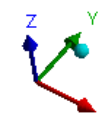
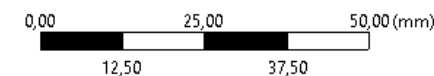
C: Steady-State Thermal
Temperature
Type: Temperature
Unit: K
Time: 1 s



50K

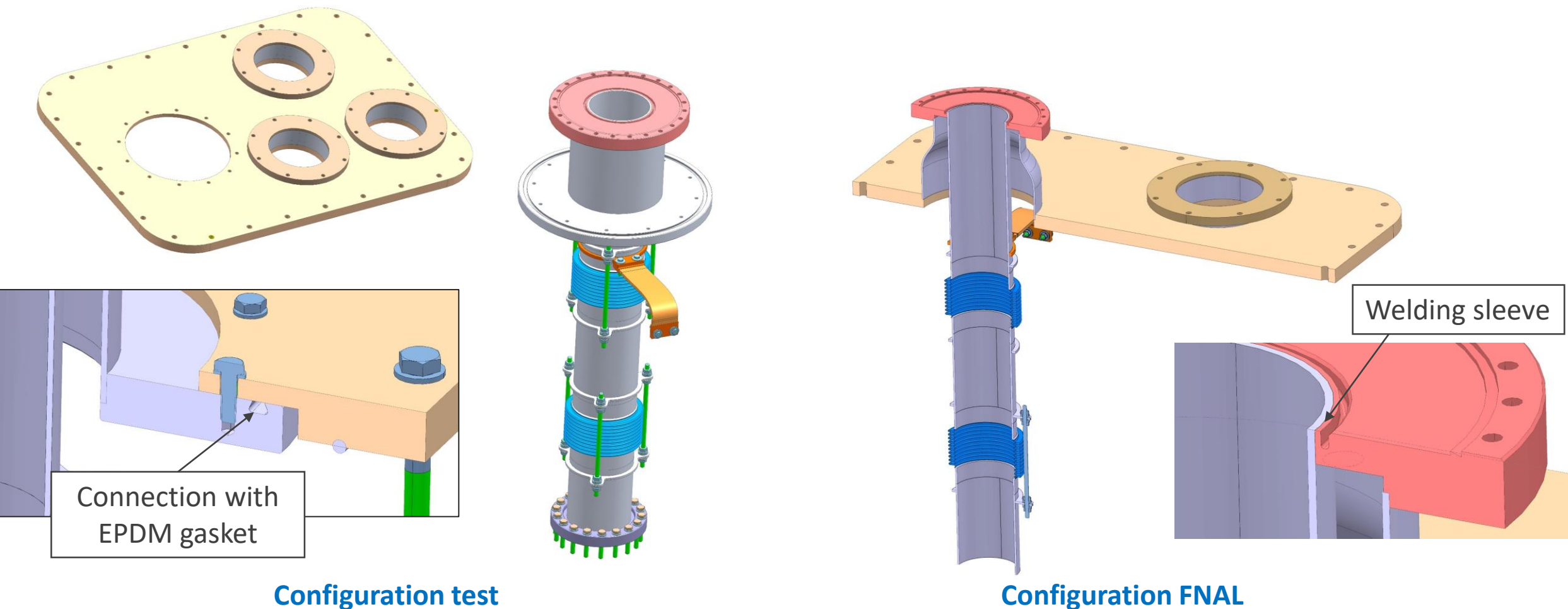


5K



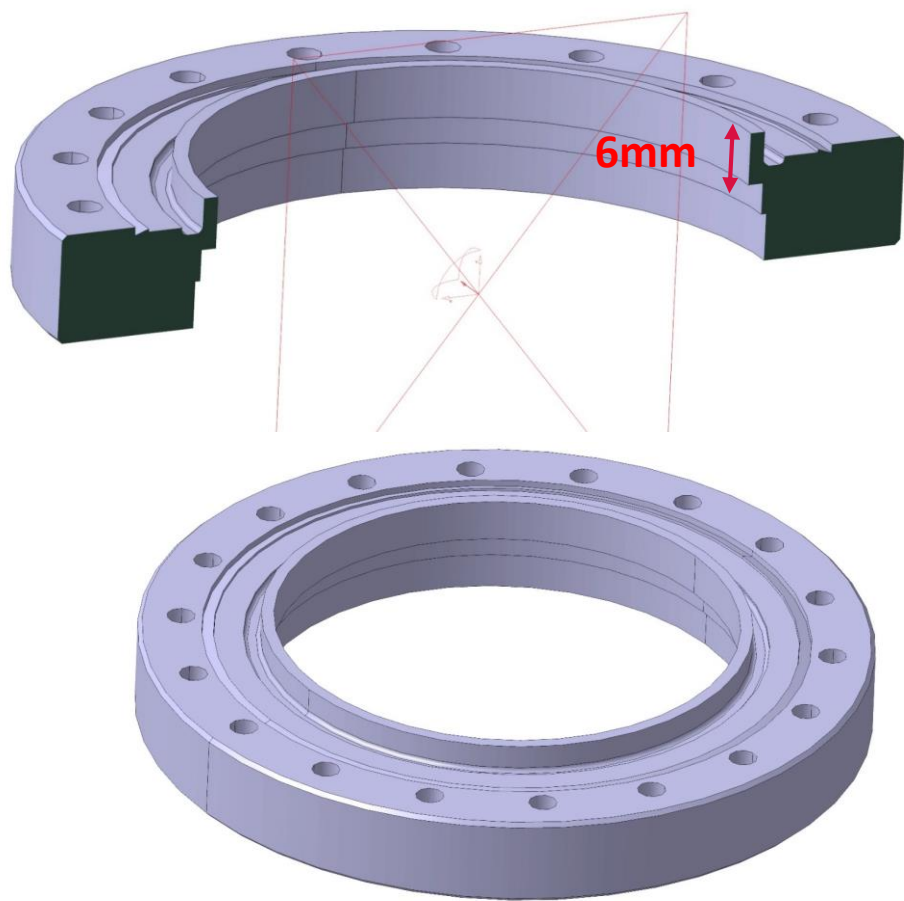
For CEA test a specific flange will be welded. The flange has a sleeve of 6mm in order to make the welding at FNAL

- ❑ A specific top port flange for the CEA test will be used.

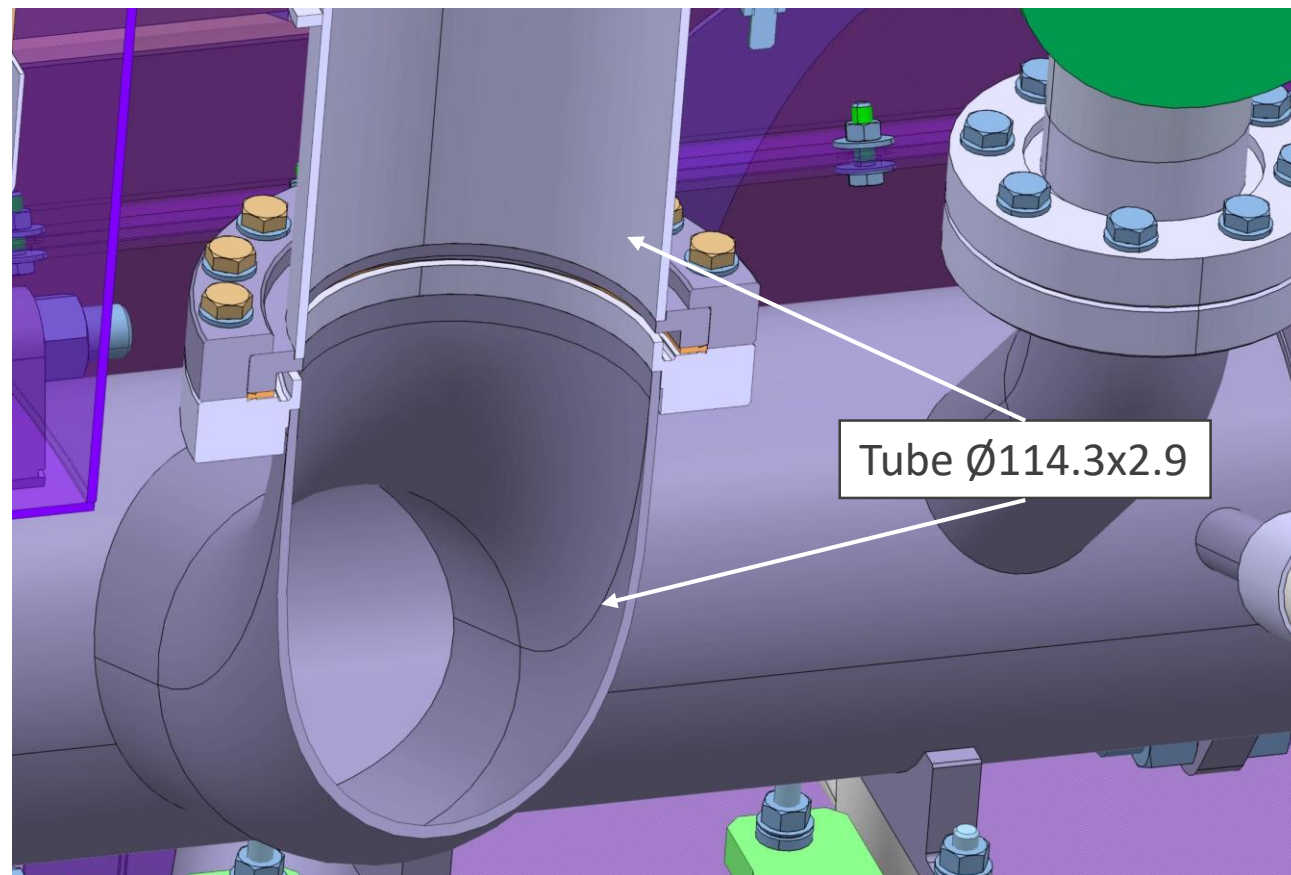


For CEA test a specific flange will be welded. The flange has a sleeve of 6mm in order to make the welding at FNAL

❑ Sleeve for the welding at FNAL



Test configuration



For CEA test a specific flange will be welded. The flange has a sleeve of 6mm in order to make the welding at FNAL

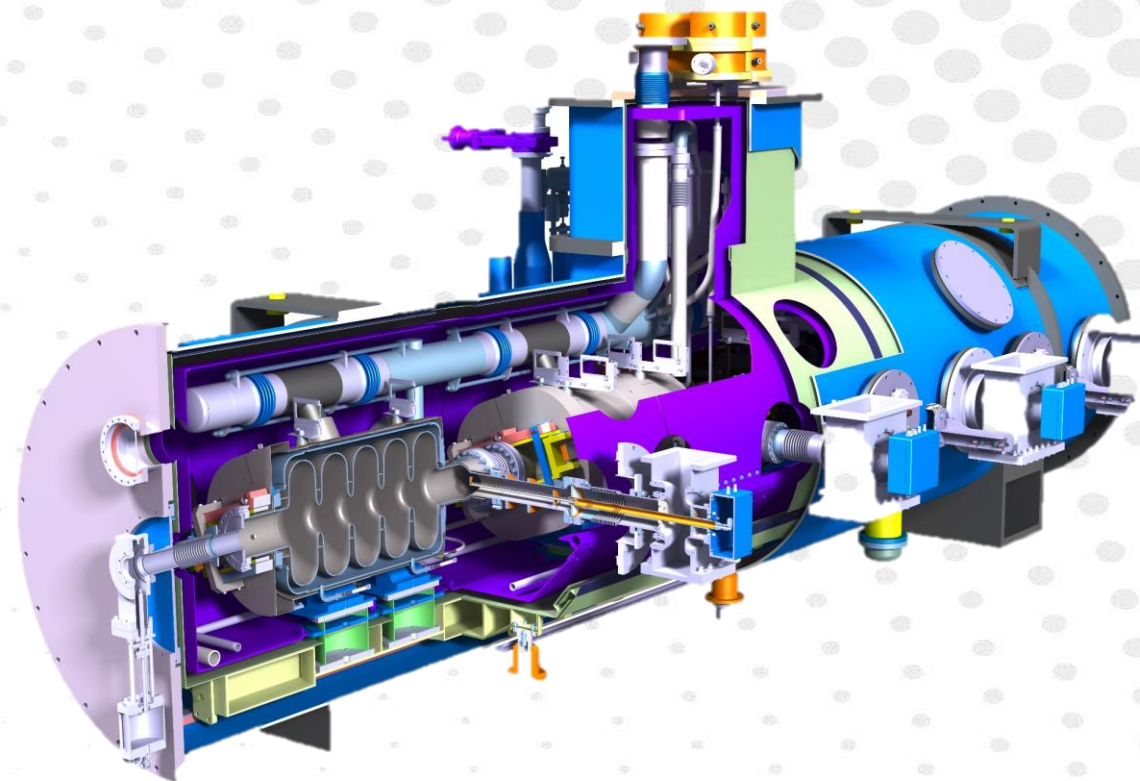
*Test configuration
With specific CF flange*

*Final configuration
Tube welded to the flange sleeve*



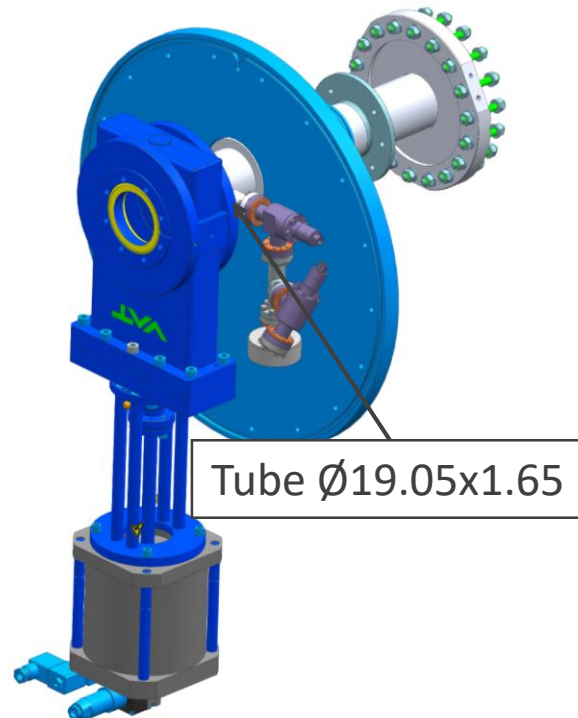
Thermal intercept connected to the 5K line

- ▶ Vacuum vessel
- ▶ Supporting components
 - Strongback and studs
 - G11 posts
 - Cavity post
 - C shaped element
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 - 5K circuitry
 - Cooling down circuitry
 - Relief line
- ▶ End pipe tube
- ▶ Thermal shield
- ▶ Magnetic shield
 - Global warm magnetic shield
 - Local cold magnetic shield

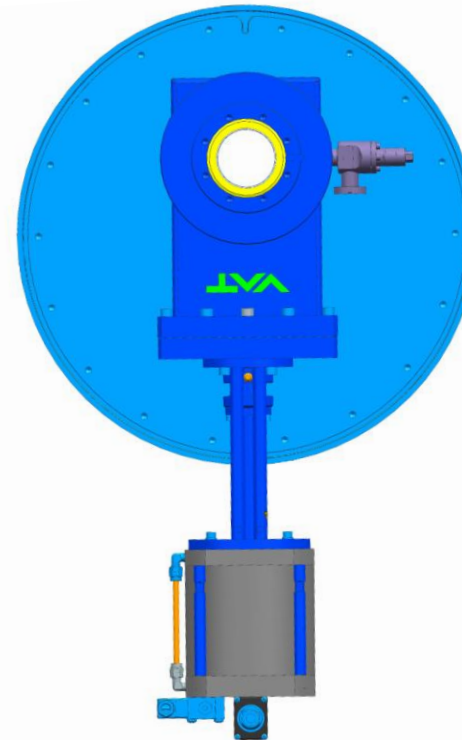


Proposition of end pipe tube modification in order to ease the clean room and the end cap assembly.

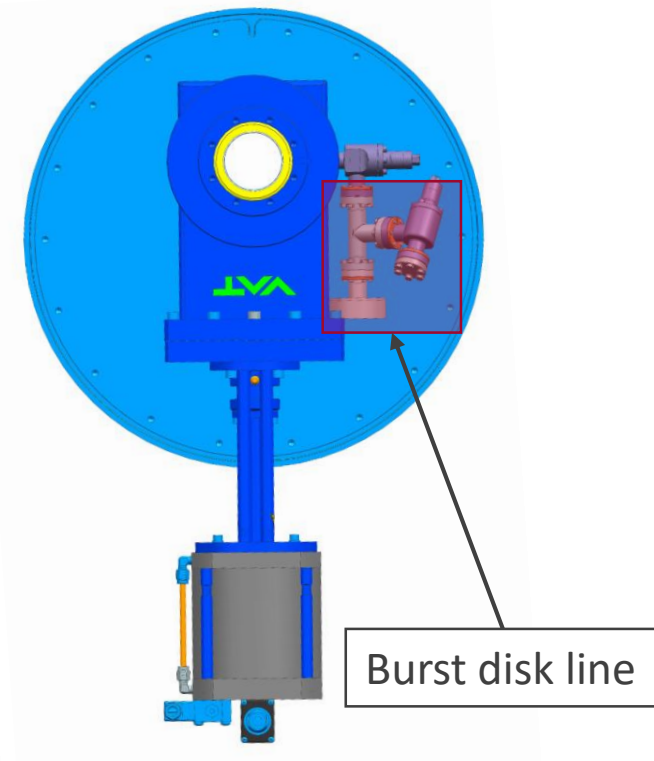
- ☐ Orientation of the burst disk line on the horizontal plane.
- ☐ The Burst disk line will be assembled after the end cap assembly.



Configuration for clean room assembly



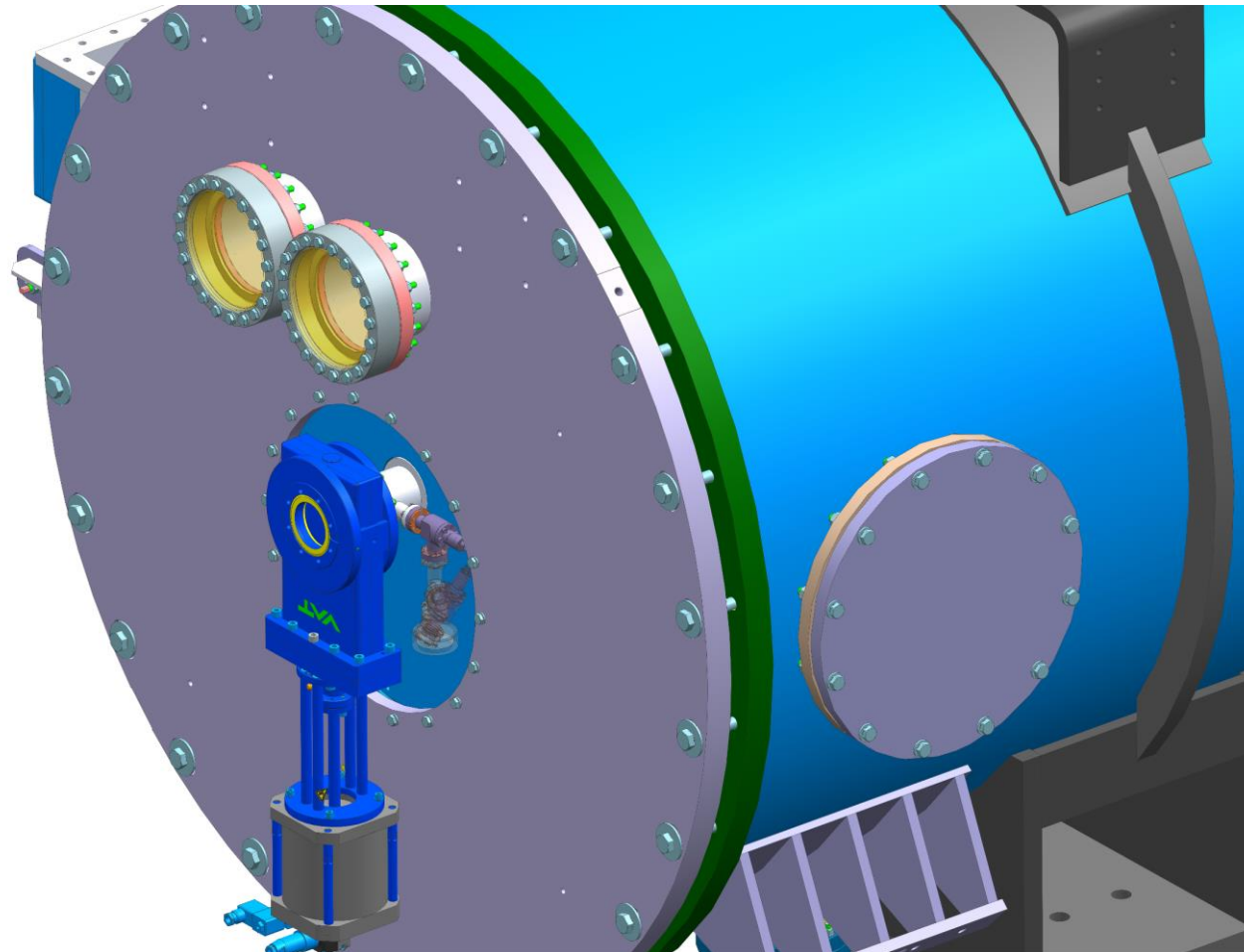
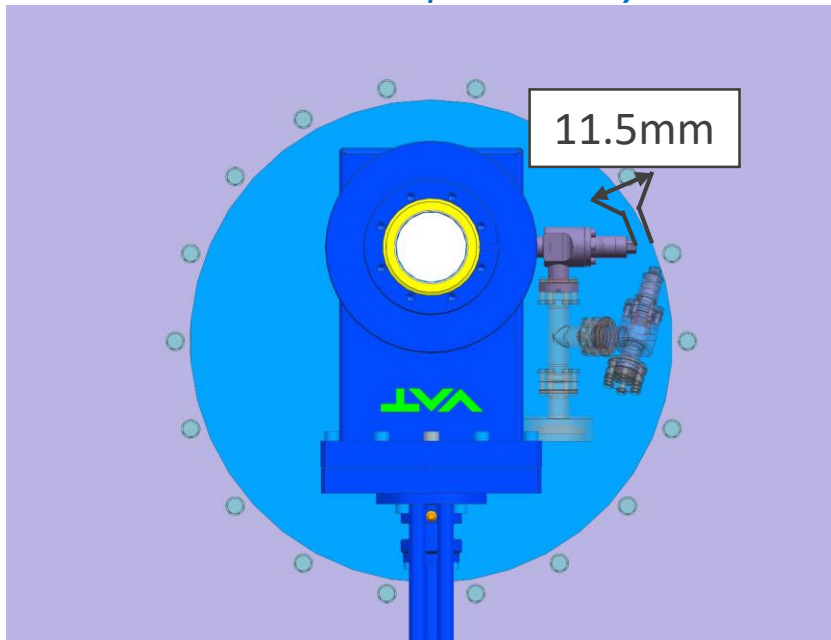
Final configuration



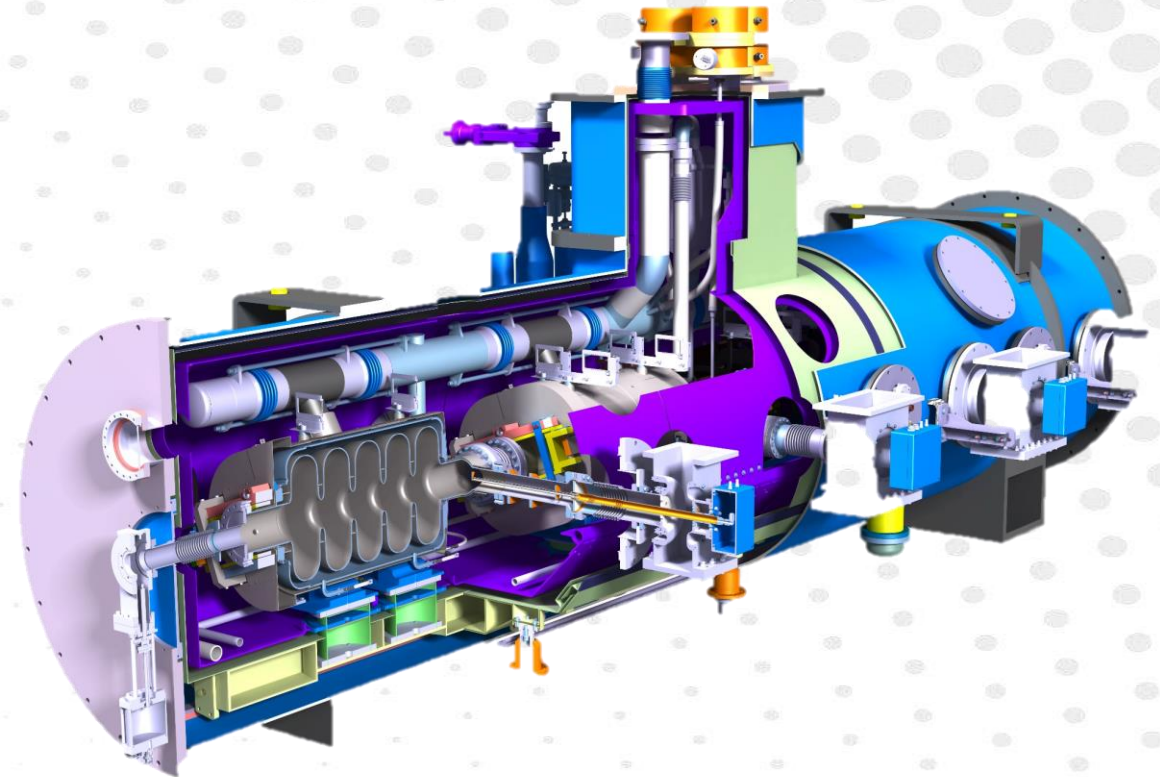
Proposition of end pipe tube modification in order to ease the clean room and the end cap assembly.

- ☐ Orientation of the burst disk line on the horizontal plane.
- ☐ The Burst disk line will be assembled after the end cap assembly.

Available space during the end cap assembly

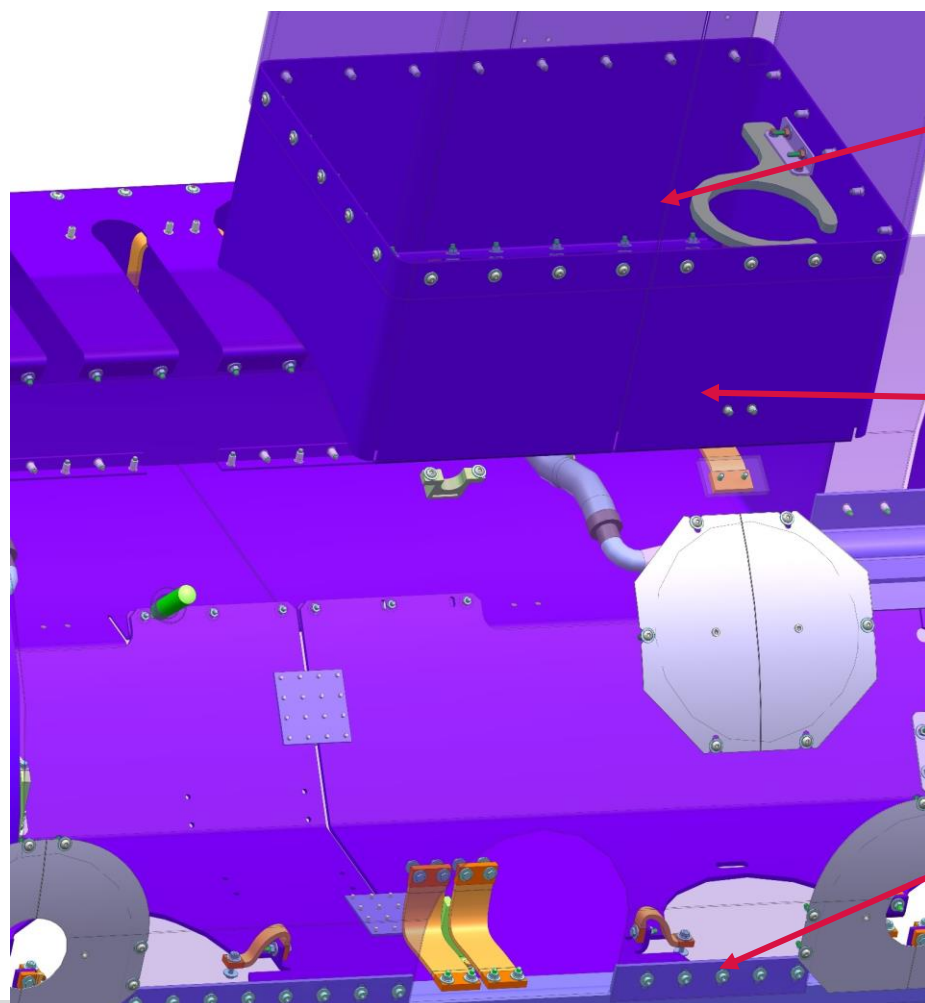


- ▶ Vacuum vessel
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 - Cavity post
 - C shaped element
- ▶ Helium circuitry
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 - 5K circuitry
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- ▶ End pipe tube
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- ▶ Magnetic shield
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Thermal shield design

- ❑ Assembly of the top part different to the HB650.
- ❑ Intermediate sleeve on the top port.

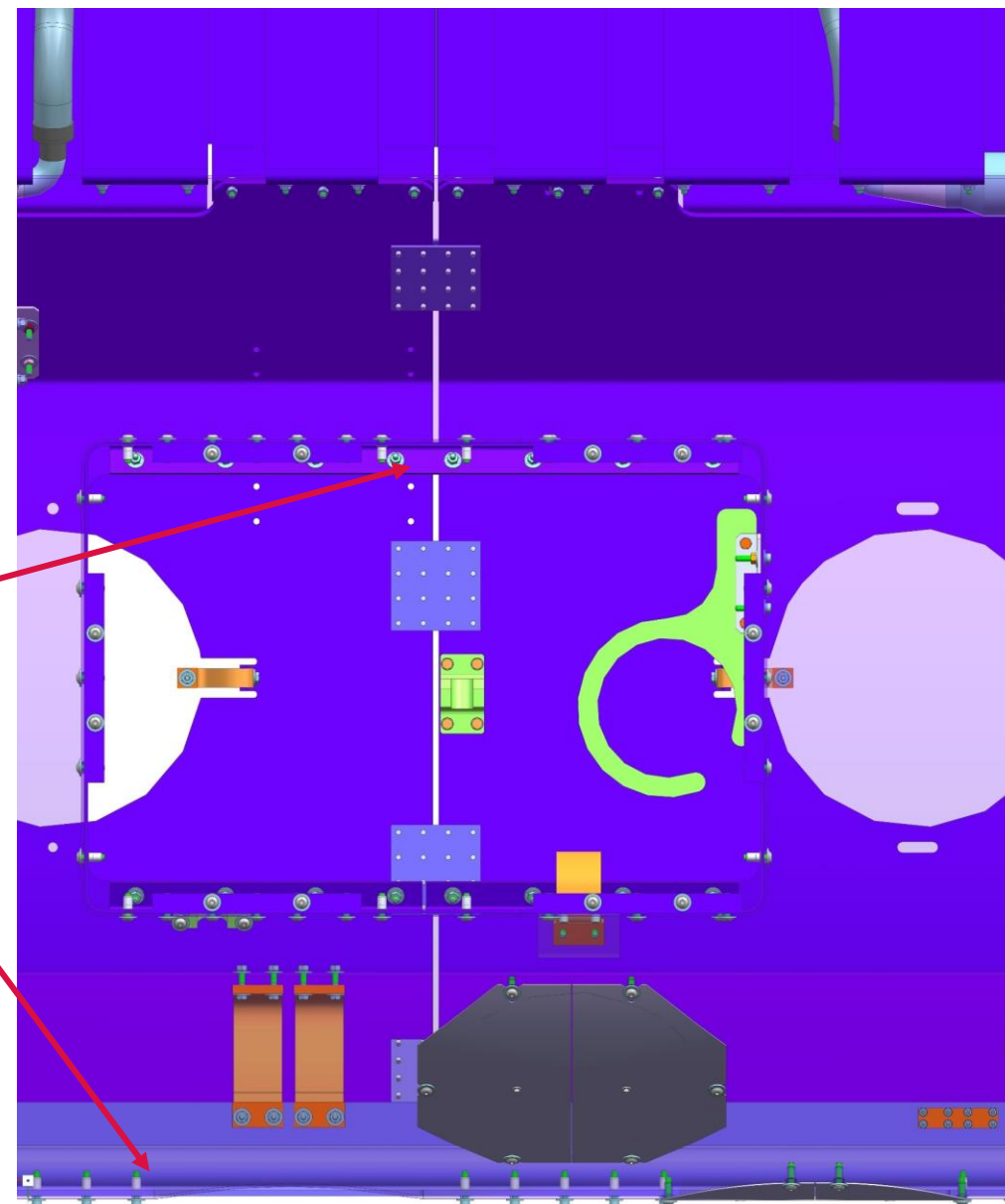


Top port assembled by screws after the assembly of the HX and relief line

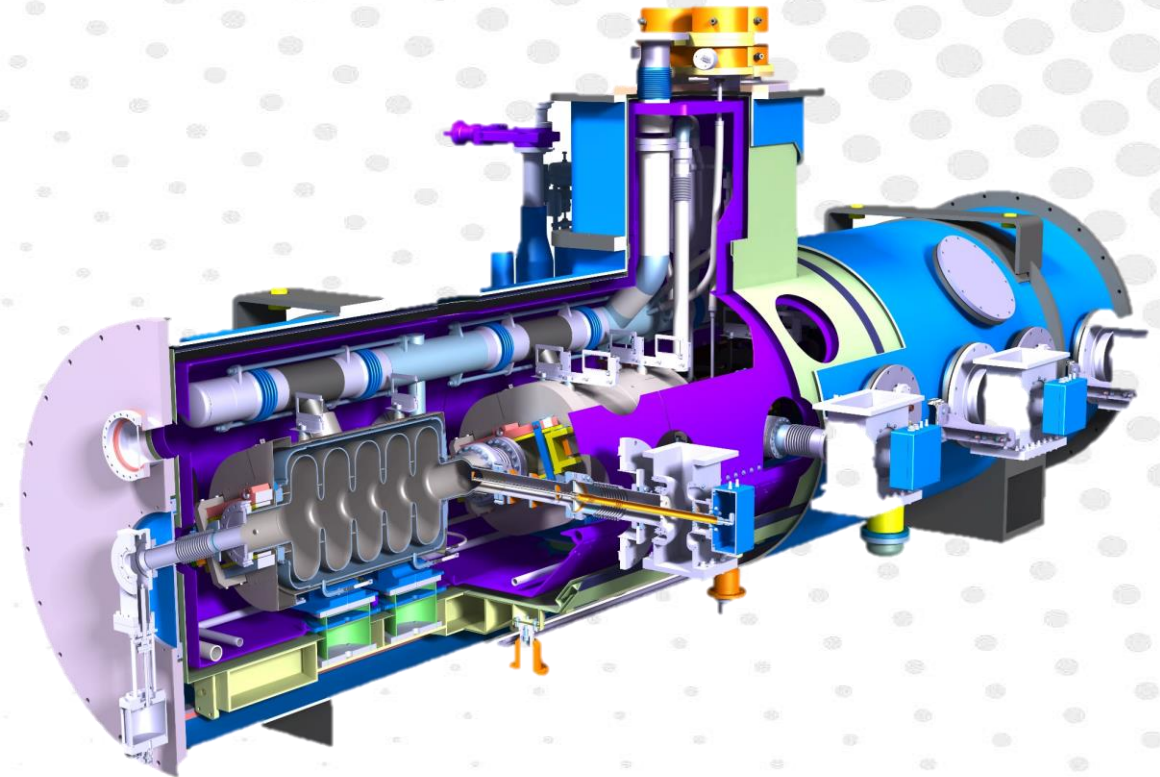
Intermediate sleeve assembled from the inside

Cooling circuitry identical to the HB650

Top part assembled by screws

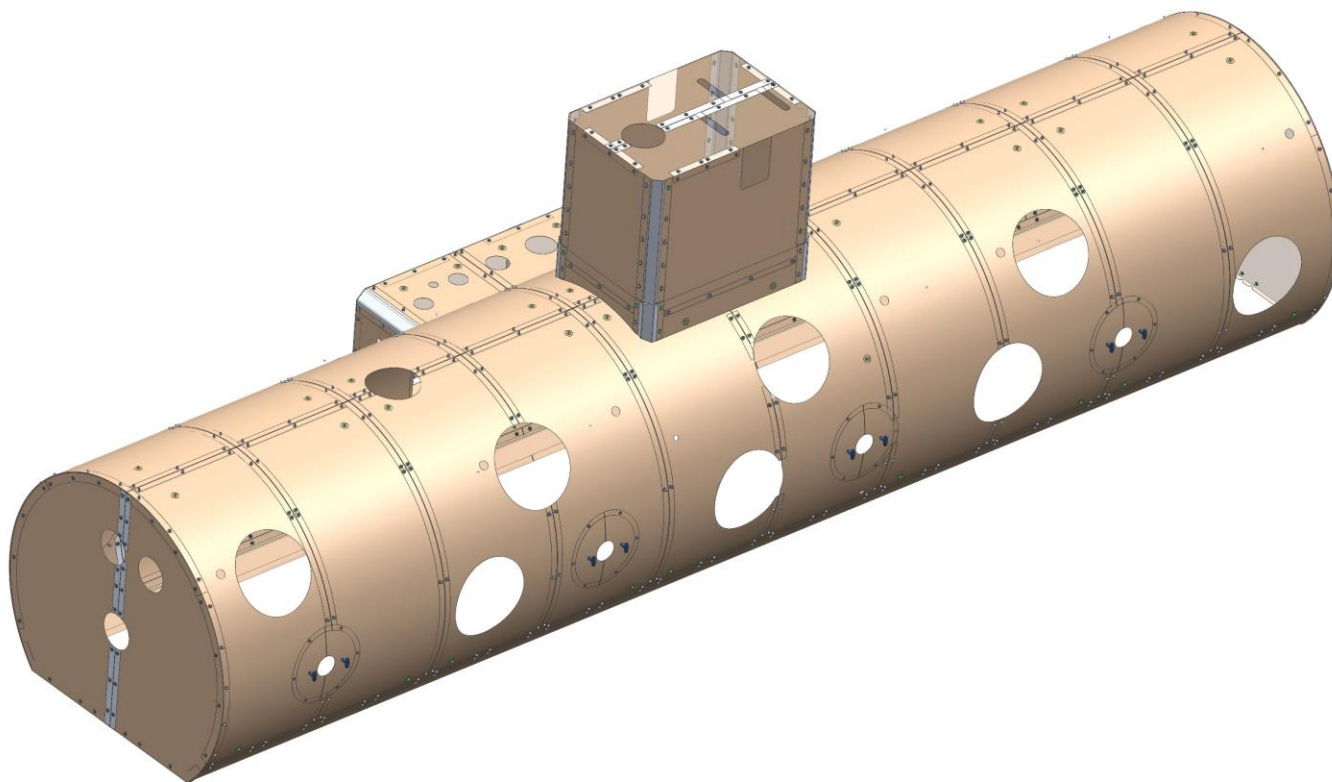


- ▶ Vacuum vessel
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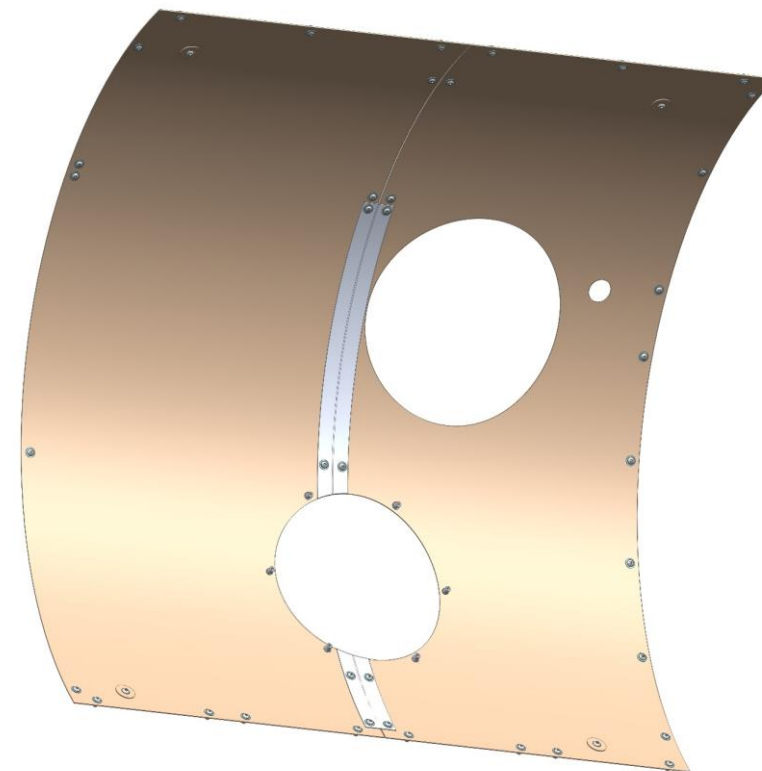
Global magnetic shield top part

- ❑ Mu-metal sheet dimensions compatible for heat treatment oven and supply.
- ❑ Cover joint between the sheet, assembled with RIVKLE.
- ❑ Interface with the vacuum vessel.



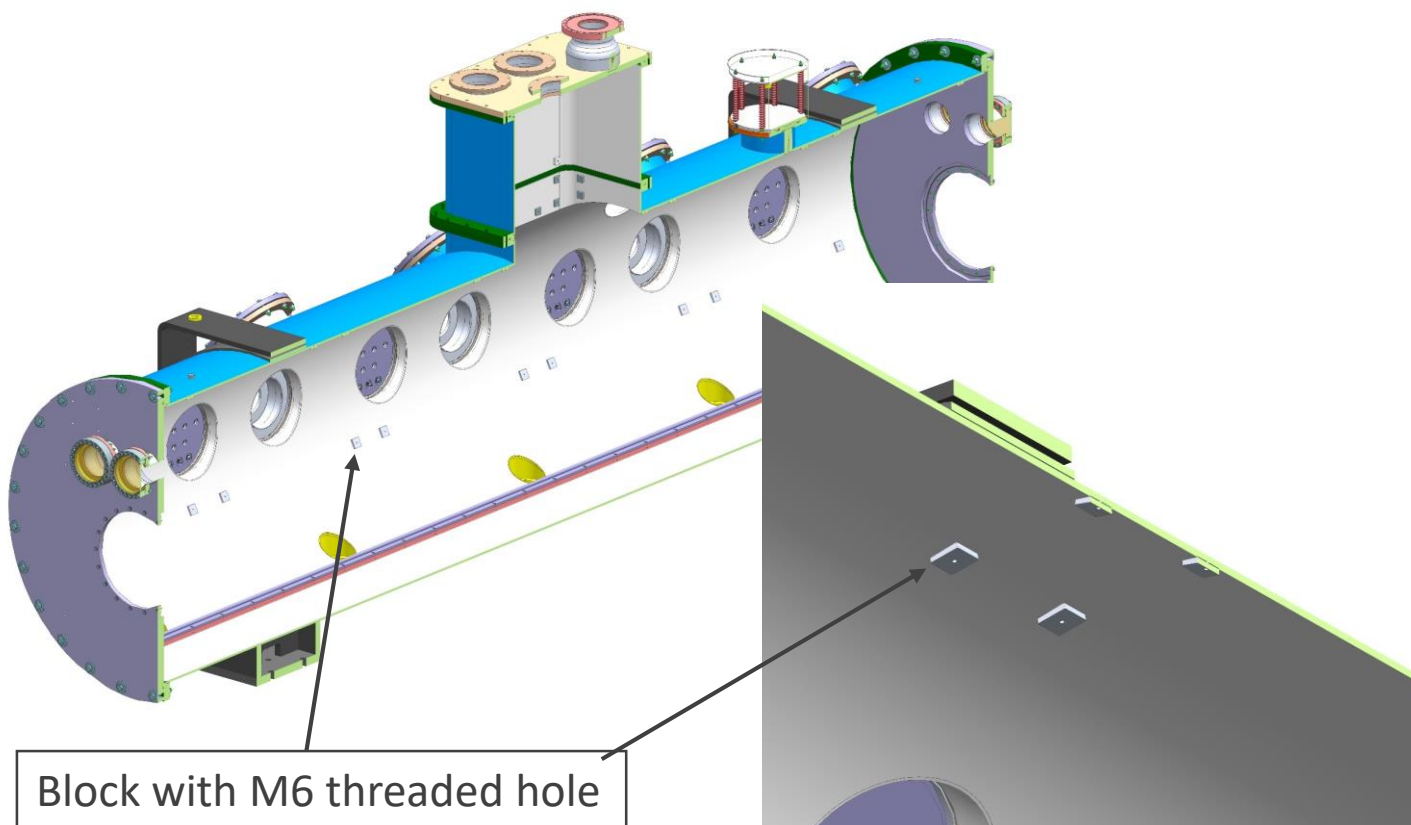
Top part fixed on the vacuum vessel

*Pair of panel pre-assembled
before assembly on vacuum vessel*

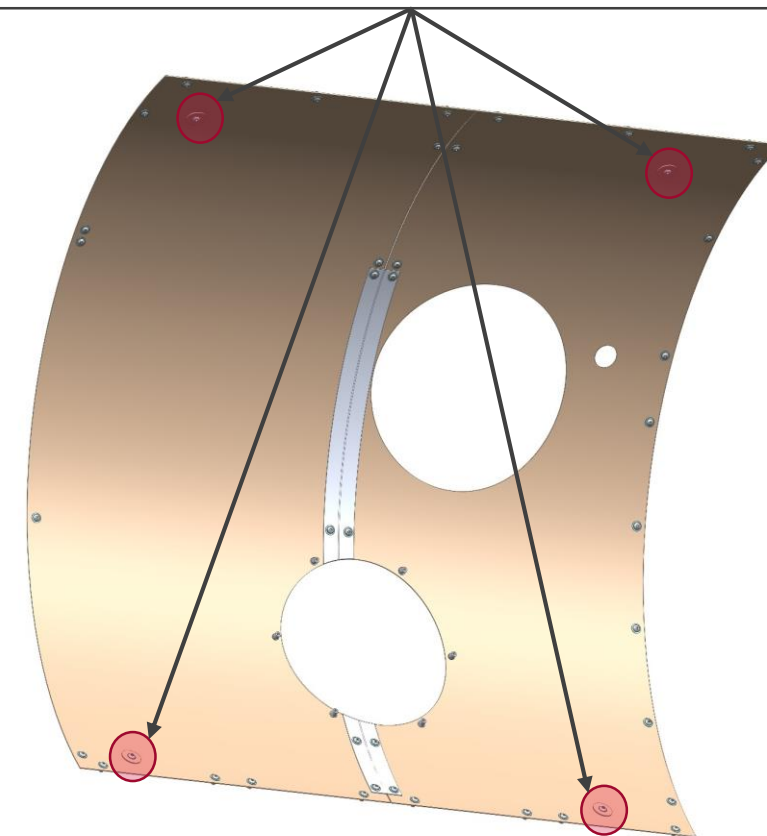


Global magnetic shield top part

- ❑ Mu-metal sheet dimensions compatible for heat treatment oven and supply.
- ❑ Cover joint between the sheet, assembled with RIVKLE.
- ❑ Interface with the vacuum vessel.

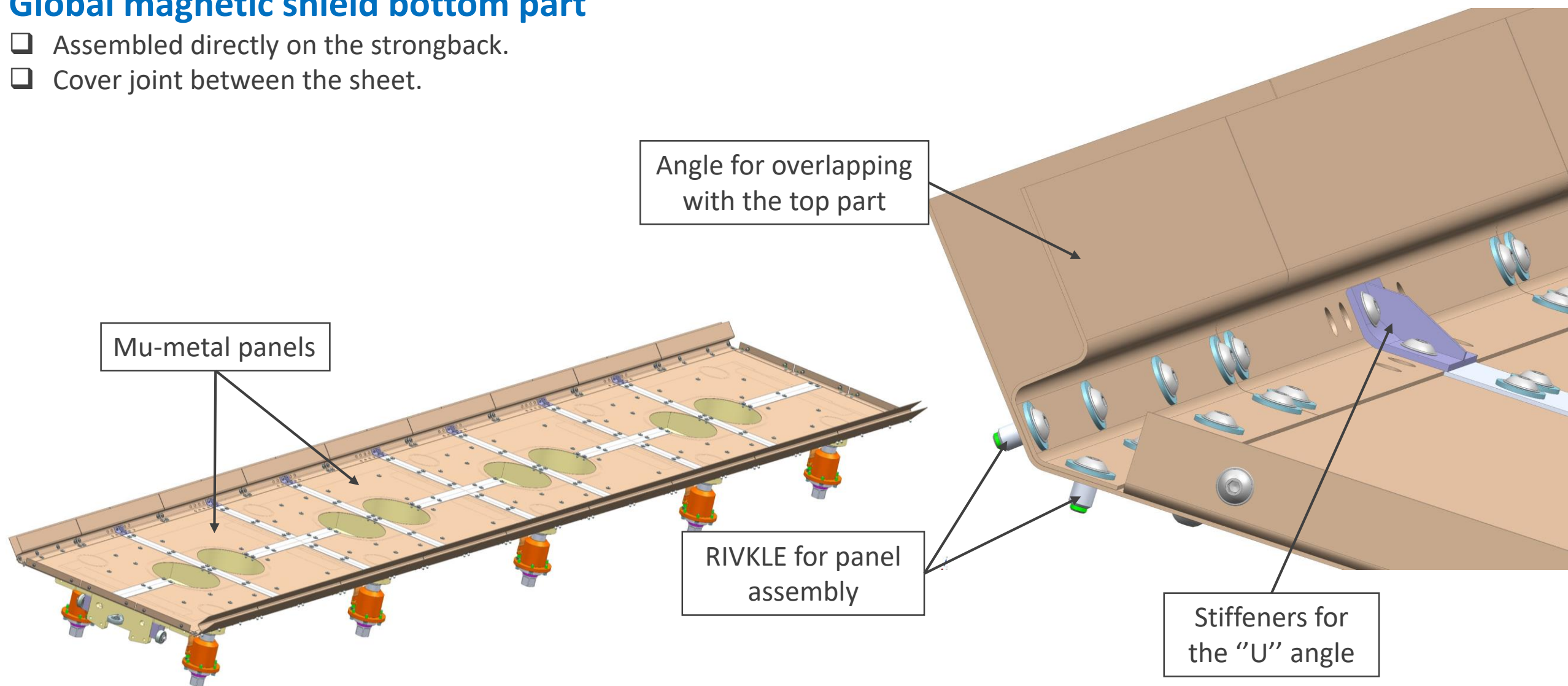


Hole Ø20mm with large mu-metal washer
For the vacuum vessel assembly



Global magnetic shield bottom part

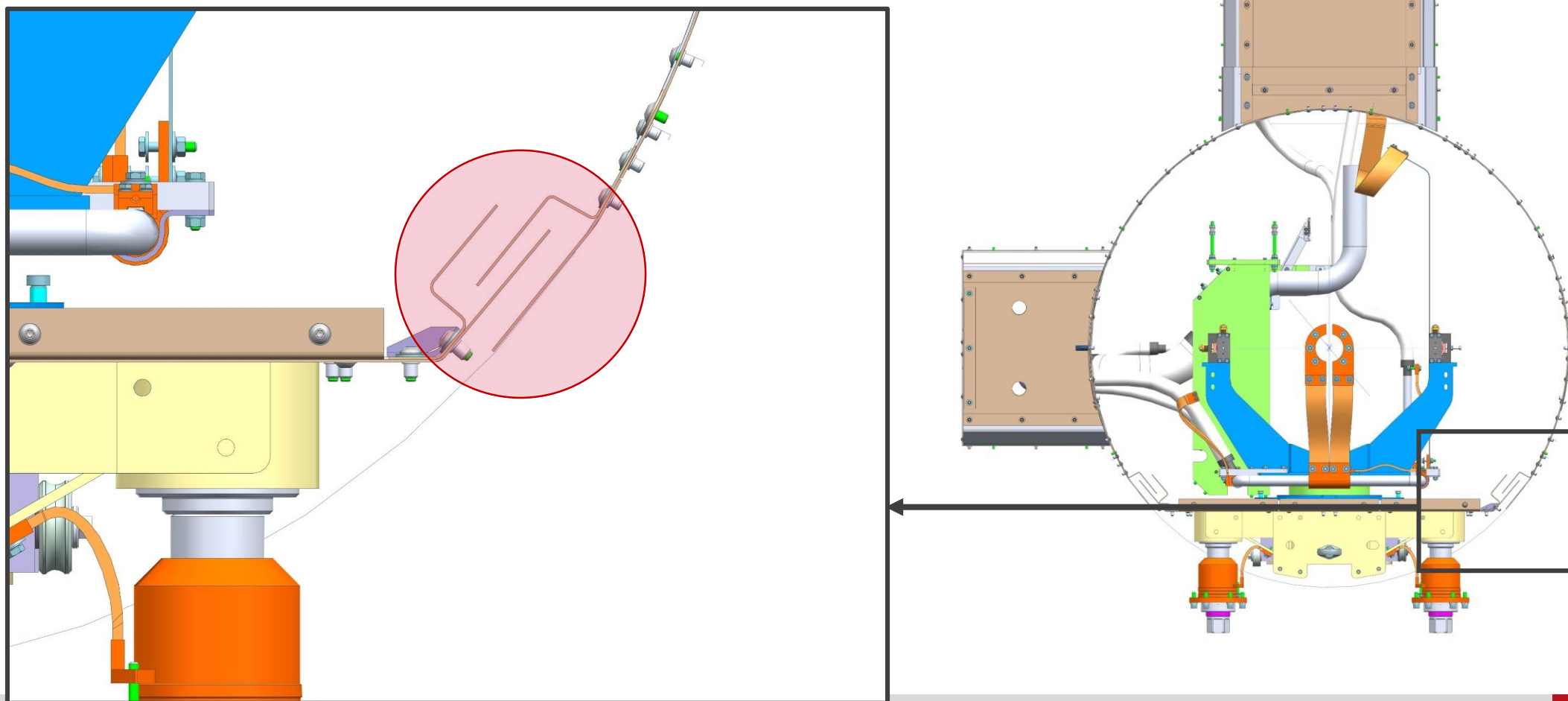
- ❑ Assembled directly on the strongback.
- ❑ Cover joint between the sheet.



Magnetic shield

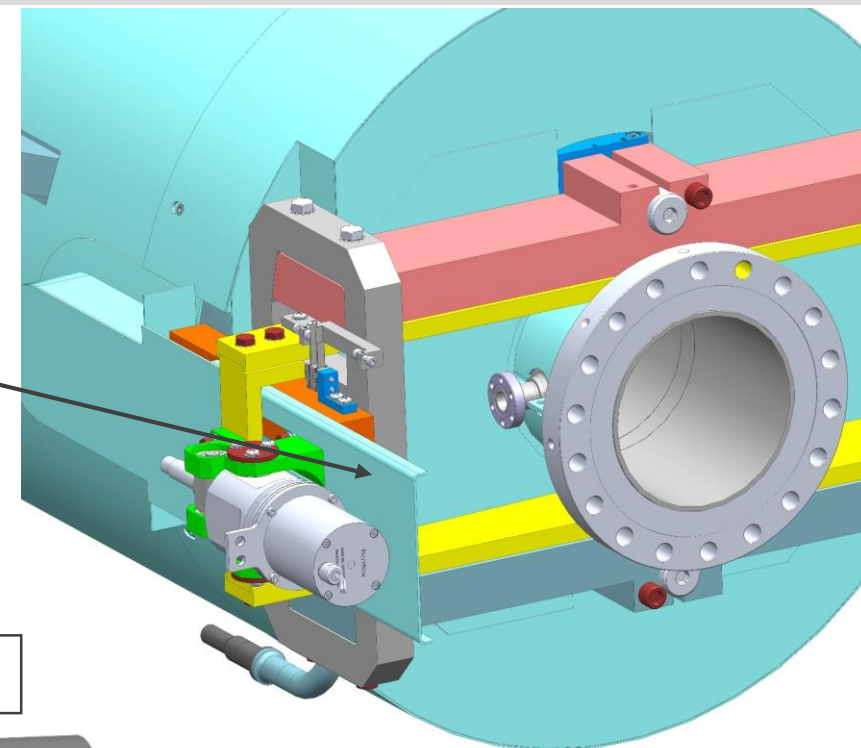
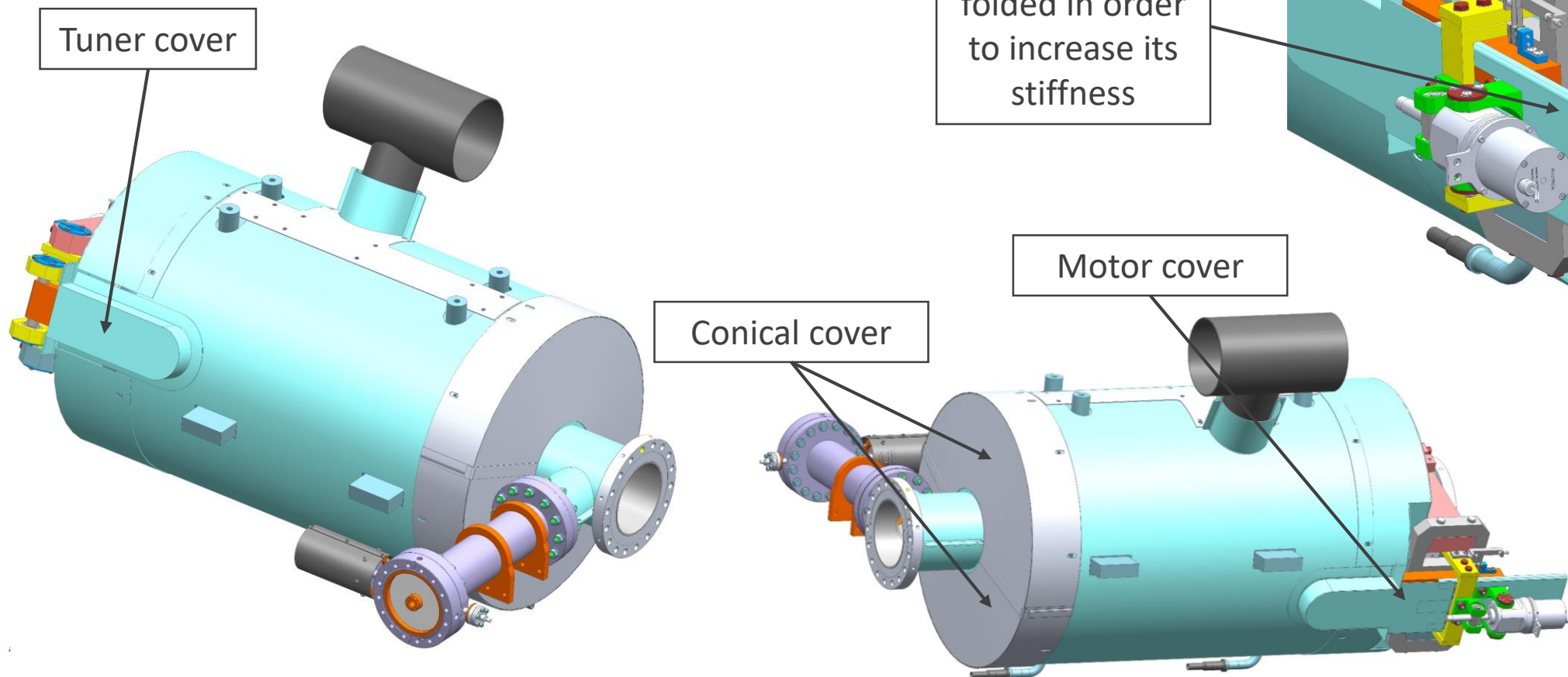
- ❑ Overlapping between the top and bottom part.

Gap in nominal cold mass nominal position



Local magnetic shield design

- ❑ Predesign completed.
- ❑ Mumetal sheet dimensions compatible for heat treatment oven and supply.
- ❑ Play of $\pm 5\text{ mm}$ for cavity length mismatch.





Thanks for your attention